BRENT WILEY, *Editor*

T. J. ESS, *Associate Editor*

JAMES D. KELLY, *Advertising Manager*

BOARD OF DIRECTORS

PRESIDENT
WILLIAM A. PERRY
Superintendent Electrical and Power Departments
Inland Steel Company
Indiana Harbor, Indiana

1ST VICE-PRESIDENT, THOMAS E. HUGHES, *Superintendent of Maintenance*, Carnegie-Illinois Steel Corporation, Duquesne, Pennsylvania

2ND VICE-PRESIDENT, FRANK E. FLYNN, *District Manager*, Republic Steel Corporation, Warren, Ohio

TREASURER, C. L. McGRANAHAN, *Assistant General Superintendent*, Jones and Laughlin Steel Corporation, Pittsburgh, Pennsylvania

SECRETARY, J. L. MILLER, *Assistant Chief Combustion Engineer*, Republic Steel Corporation, Cleveland, Ohio

PAST PRESIDENTS: JULIUS A. CLAUSS, *Chief Engineer*, Great Lakes Steel Corporation, Ecorse, Michigan

C. CLARKE WALES, *Vice-President*, Hamilton Bridge Company, Ltd., Hamilton, Ontario, Canada

HONORARY DIRECTORS: JAMES FARRINGTON, *Electrical Superintendent*, Wheeling Steel Corporation, Steubenville, Ohio

A. C. CUMMINS, *General Superintendent*, Youngstown District, Carnegie-Illinois Steel Corporation, Youngstown, Ohio

WALTER H. BURR, *Electrical Superintendent*, Lukens Steel Company, Coatesville, Pennsylvania

DIRECTOR-AT-LARGE, P. F. KINYOUN, *Combustion Engineer*, Bethlehem Steel Company, Lackawanna, New York

DIRECTORS: FREEMAN H. DYKE, *Superintendent Blooming, Bar, and Hot Strip Mills*, Wheeling Steel Corporation, Steubenville, Ohio

A. R. DIBBEN, *Assistant Electrical Superintendent* Youngstown Sheet and Tube Company, East Chicago, Indiana

GEORGE C. PFEFFER, *Superintendent of Power*, Florence Pipe Foundry and Machine Company, Florence, New Jersey

W. J. WILSON, *Chief Electrician*, American Cast Iron Pipe Company, Birmingham, Alabama

I.N. TULL, *Electrical Superintendent*, Republic Steel Corporation, Cleveland, Ohio

STEPHEN M. JENKS, *General Superintendent*, Gary Works, Carnegie-Illinois Steel Corporation, Gary, Indiana

L. J. GOULD, *Assistant Chief Engineer of Construction*, Bethlehem Steel Company, Bethlehem, Pennsylvania

R. S. SHOEMAKER, *Lubrication Engineer*, American Rolling Mill Company, Middletown, Ohio

C. H. WILLIAMS, *Assistant Chief Engineer*, Pittsburgh District, Carnegie-Illinois Steel Corporation, Pittsburgh, Pennsylvania

Managing Director
BRENT WILEY
Empire Building, Pittsburgh, Pennsylvania

IRON AND STEEL ENGINEER

OCTOBER • 1941

VOL. XVIII NO. X

In This Issue

Filters and Strainers for the Steel Industry—By George P. Dempler, Cuno Engineering Company, Pittsburgh, Pennsylvania 25

Fundamental Considerations in Supplying Power to Arc Furnaces—By F. M. Starr and O. B. Falls, Central Station Engineering Department, General Electric Company, Schenectady, New York 30

Discussion: Fundamental Considerations in Supplying Power to Arc Furnaces—Presented by H. P. St. Clair, L. W. Clark, C. B. Morin, F. W. Brooke, B. M. Jones, C. M. Stearns, and F. M. Starr 42

Surge Voltage Tests on Electric Arc Furnaces—By Z. R. Whitehouse, Electrical Superintendent, Republic Steel Corporation, Canton, Ohio, and C. C. Levy, Industry Engineering, Metal Working Section, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pennsylvania 51

Discussion: Surge Voltage Tests on Electric Arc Furnaces—Presented by J. E. Hobson, C. M. Foust, L. S. Steiner, Samuel Arnold, 3rd, E. W. Bohene, B. M. Jones, and C. C. Levy ... 59

Steel-Making Electric Furnaces of the United States—By T. J. Ess 65

The Sawing of Metals—By C. M. Thompson, Henry-Disston and Sons, Inc., Philadelphia, Pennsylvania 72

Discussion: The Sawing of Metals—Presented by J. F. Black, R. W. Tilford, L. F. Coffin, C. M. Thompson, and Louis Moses 75

Rolls and Roll Design—By C. Elms, Pittsburgh Rolls Corporation, Pittsburgh, Pennsylvania 68

Latest Design and Equipment for the Industry 93

Items of Interest 106

Index to Advertisers 23

Published Monthly by

ASSOCIATION OF IRON AND STEEL ENGINEERS

Entered as second-class matter January 25th, 1924, at Pittsburgh, Pa., under the Act of March 3rd, 1879

Statements and opinions given in articles and papers appearing in "Iron and Steel Engineer" are the expressions of contributors, for which the Association of Iron and Steel Engineers assumes no responsibility.

Copyright, 1941, The Association of Iron and Steel Engineers

Single Copy Foreign Prepaid $2.00 Single Copy $1.50

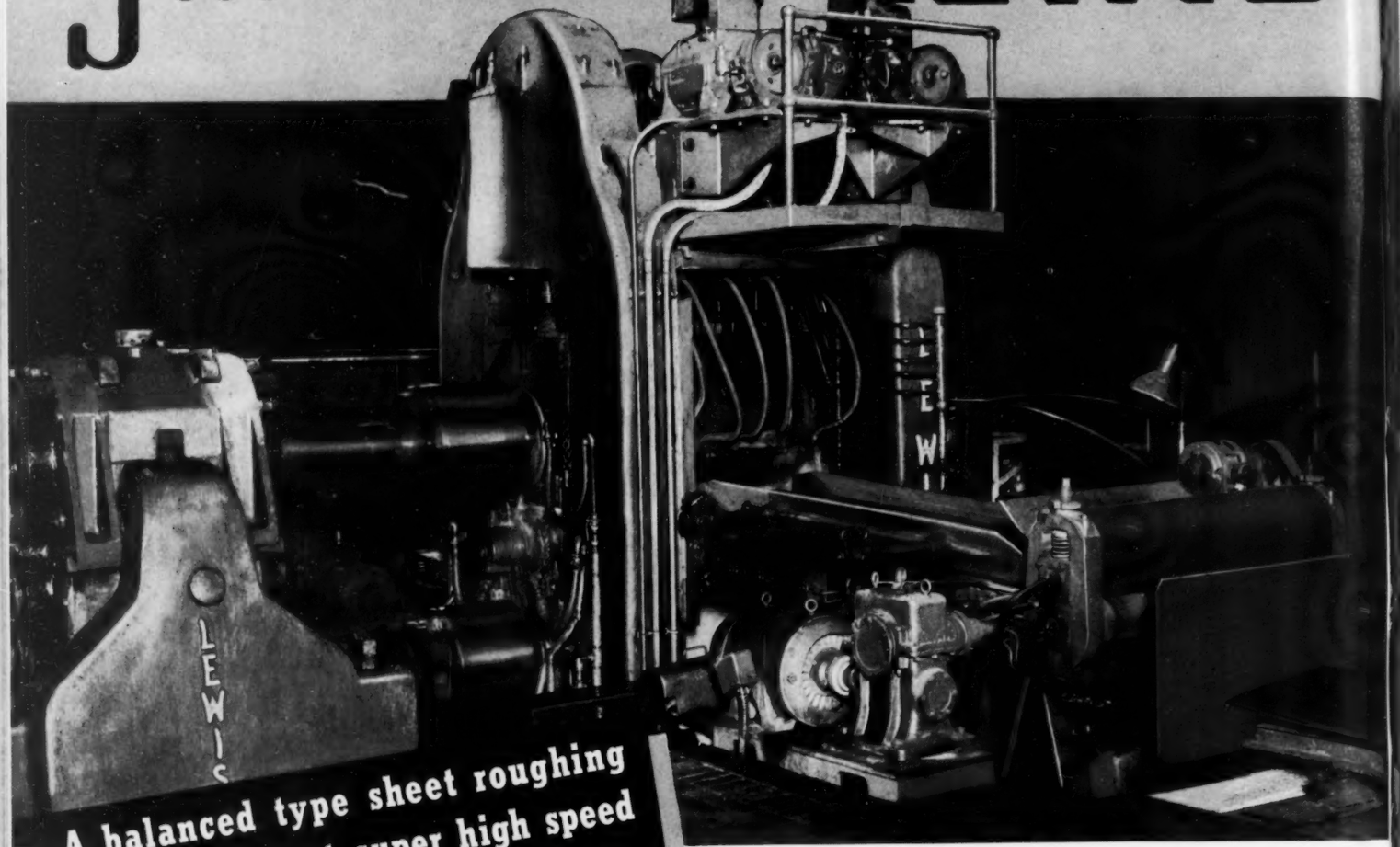
Subscription price in U. S. & Canada ..... $ 7.50 per year

Subscription price in foreign countries ..... $10.00 per year

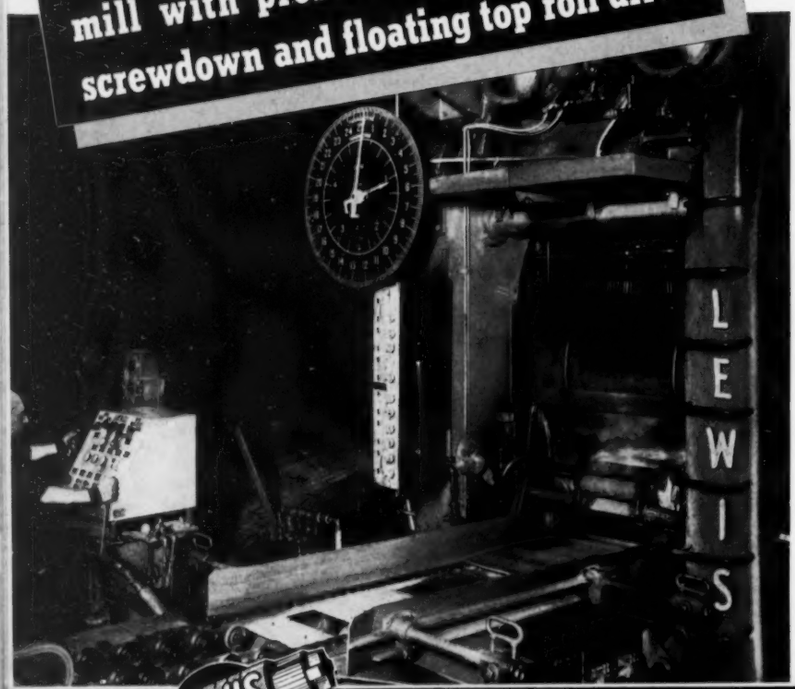
PLASTIC BINDING U. S. PATENT NO. 1970285 LICENSE NO. 50

A NEW 3 HIGH MILL by LEWIS

ADVERTISING PAGES REMOVED



A balanced type sheet roughing mill with preset super high speed screwdown and floating top roll drive



Special Features

It appreciably increases breakdown production of heavy sheet bar.

It is equipped with a floating top and bottom roll drive of new design.

No springs are used in balancing the top or middle roll, reducing maintenance costs.

Middle roll balance mechanism is incorporated in middle roll chocks, further reducing maintenance.

The floating type top roll drive eliminates jump in both top and bottom rolls.

This new mill is still another example of continued improvement and progress of Lewis Rolling Mill Machinery.

LEWIS

LEWIS FOUNDRY & MACHINE

DIVISION OF BLAW-KNOX CO.

PITTSBURGH, PA.

FILTERS and STRAINERS for the Steel Industry

By George P. Dempler

THE CUNO ENGINEERING CO.

PITTSBURGH, PENNA.

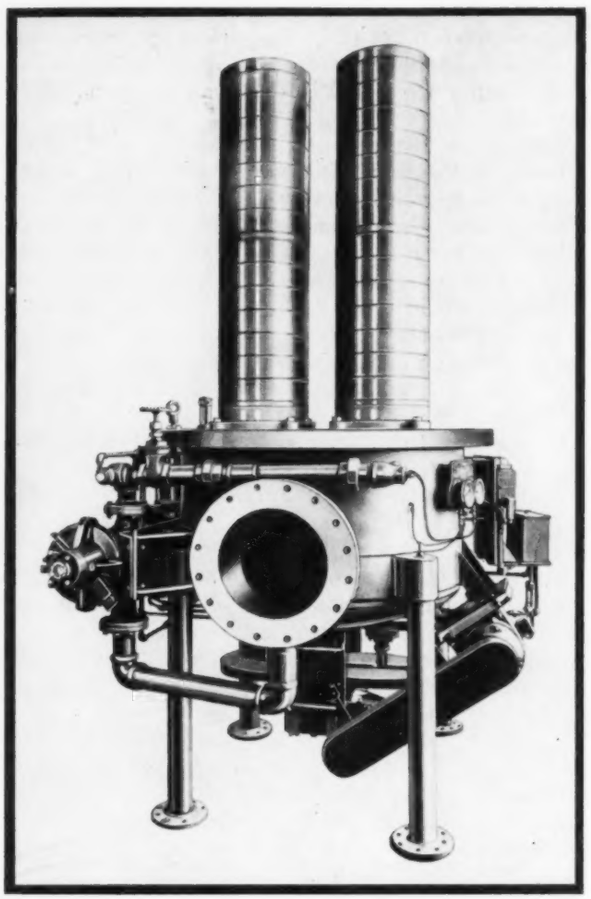


Figure 1—This view of backwash type filter (with upper cover removed) shows the cartridge construction of the unit.

▲ FILTERS play a very important part in the successful operation of the modern steel plant by removing undesirable foreign matter from the many fluid systems. They must be carefully engineered to perform the many services expected of them under a variety of conditions requiring many types and sizes.

This article will consider only pressure filters, usually installed as integral parts of fluid systems, as used in such steel plant producing units as by-product coke plants, open hearths, and bloom, billet, structural, bar, rod, wire and strip mills. No mention is made of coarse primary strainers located at raw water sources or of sand filters used to clarify water for such purposes as drinking and boiler feed.

The rapid development of high speed tandem strip, rod and wire mills, has brought about the necessity for positive, uninterrupted operation of all auxiliary equipment. Flow through fluid systems cannot be stopped for filter cleaning. A higher degree of filtration is required for adequate protection of precision parts. Contamination resulting from carelessness in servicing strainers which must be opened for cleaning cannot be tolerated. Finally, the space required for duplex strainers frequently prohibits their use.

Paralleling these developments, progressive filter manufacturers have introduced filters which clean themselves continuously and which automatically discharge accumulated sludge at periodic intervals without interruption to flow. Such filters operate continuously and are never opened except for inspection or repair during normal overhaul periods.

For the removal of solids from water used for descaling, roll body coolant, hydraulic systems, water lubricated bearings, etc., filters of the back-wash type are used because of their ability to resist the abrasive action of the sand, scale and fine dirt usually present in appreciable quantities. The elements of all such strainers, whether wire wound or of wire mesh or perforated porcelain disc construction, are cleaned by reversing the flow successively through each section, thus dislodging and disposing of accumulated solids.

Illustrated in Figure 1 is a backwash type of filter manufactured by our company. The upper sump is removed, showing cartridge construction. The element consists of one or more cylindrical cages, the outer surface of which is cut with a screw thread and wound with a round wire. The fluid to be filtered enters the chamber or sump surrounding the filter cartridge and passes radially inward between the wires, depositing on these wires all solids too coarse to pass. From the interior of the cartridge, the filtered fluid moves downward to the outlet connection at the bottom. Backwash fluid is picked up from the outlet connection and is delivered by a small booster pump to a slowly rotating backwash nozzle, at a slightly higher pressure than exists outside the cartridge. As each section of the element thus encounters a momentary reversal of flow,

all solids are dislodged and because the backwash is returned to the system, there is no loss of fluid. The solids which accumulate in the base are periodically drained through a manually or mechanically operated blow-off valve. Floating sludge is simultaneously removed through a top blow-down.

For many steel mill services, backwash filters are not generally used because the quantity and nature of solids to be removed is such that filters of more simple and economical construction can be applied. These services include individual and centralized lubricating systems for oil type roll neck bearings, gear reducers, pinion stands and motor bearings; also grease, fuel tar and various processing liquids.

A type of filter extensively used on individual and centralized lubricating systems is our "edge" type, which is continuously cleanable, manually or automatically, without interruption of the flow of liquid through it. The filter element (see Figure 2) consists of a stack of wheel shaped discs, each one accurately separated from the next by a thin metal spacer. The thickness of the spacer determines the degree of filtration. The stack of discs, mounted on a rotatable shaft, is closed at one end, the spaces between disc "spokes" forming passages within the cartridge which are open at the other end to the outlet passage.

Fixed alongside the stack of discs is a rod holding knifelike stationary cleaner blades which extend into the slots between discs. The liquid to be filtered is introduced into the space surrounding the filter element in the sump or housing, and is forced by the differential pressure between the inlet and the outlet, to flow through the slots between discs to the passages within the filter element and thence to the outlet. All solids larger than the thickness of the spacer pieces are retained on the outer edges of the discs.

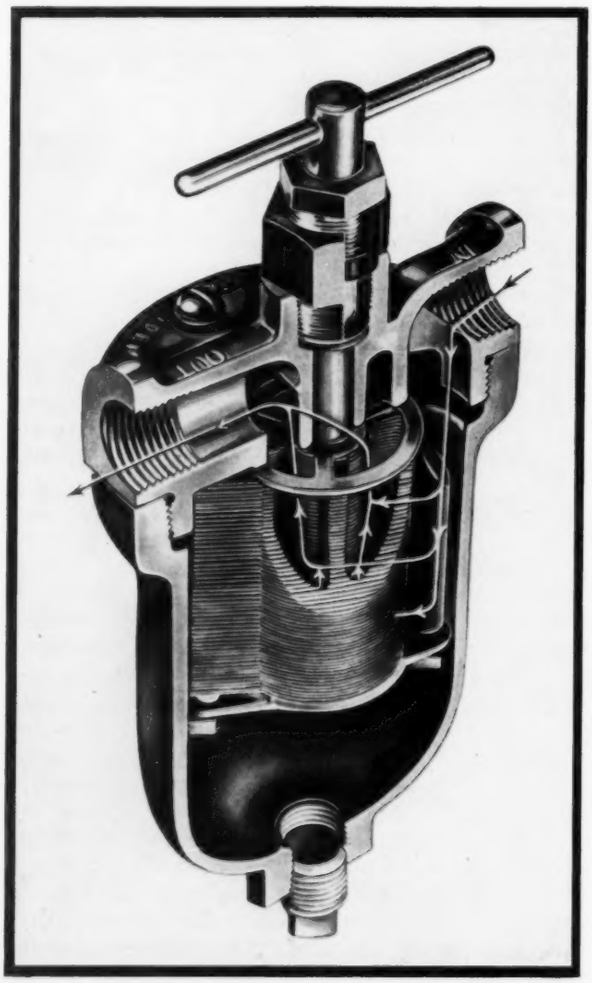
When the cartridge is turned through a complete revolution by means of the external handle or by motor drive, all solids collected on the surface are combed out by the stationary cleaner blades and settle to the bottom of the sump from which they can be periodically removed.

Spacing, or the size of the openings in the filter element, is the first question to be decided. Where spray nozzles are to be protected, the general rule is to select a filter spacing one-half the size of the nozzle orifice. On bar mills, for example, where nozzles with $\frac{1}{8}$ in. openings are commonly used, a filter built to .062 in. spacing would normally be specified. Nozzles with smaller orifices are now being used on many strip mills and for the $\frac{1}{32}$ in. openings now becoming prevalent, a filter with .015 in. spacing is required for adequate protection.

In selecting the proper spacing for other services, consideration should be given to such factors as the type of equipment to be protected, the viscosity of the fluid to be filtered, and the amount and nature of solids to be removed.

The size of the filter required for a particular application depends upon the amount of free filtering area needed to pass the required rate of flow at a velocity through the filter openings which will result in a pressure drop across the filter no greater than the maximum allowable.

The relationship between velocity through the filter openings and pressure drop across the filter varies with the spacing of the element and the viscosity of the liquid. It also differs greatly for various types of filters. The backwash type filter, illustrated and described in



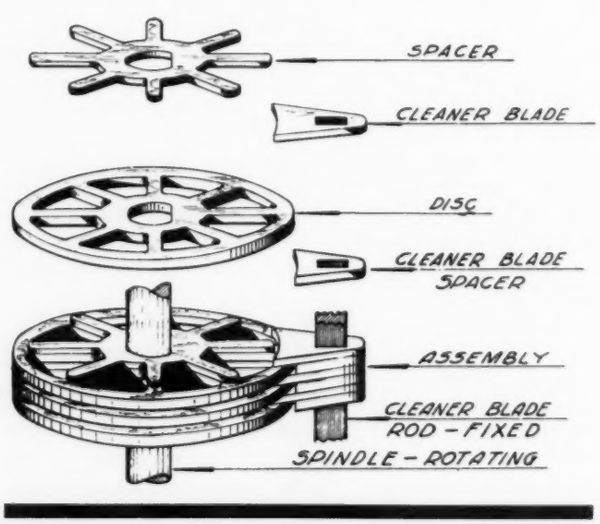


Figure 2—Details of construction of the edge type filter *(left)* are shown by the sketch below.

this article, creates a pressure drop of approximately 3 lb. per sq. in. when handling mill service water under average conditions at a slot velocity of 1 ft. per sec. and 4 lb. per sq. in. at 2 ft. per sec. Because the question of determining the proper slot velocity through the openings of the filter element involves a judgment factor, it is best to be guided by the recommendations of the filter manufacturer.

After the proper velocity through the filter openings has been established, the free filtering area needed to handle the required flow is determined by applying the formula:

$$A = \frac{F}{3.12V}$$

where A = free area in square inches
F = flow in gallons per minute
V = velocity through filter openings in feet per second

When the required free area is known, it is then a simple matter to choose a filter of the correct size. Next comes the question of deciding upon the materials of construction for the filter internals. Plain steel internals are entirely satisfactory for lubricating oil services. Under conditions which would cause rusting or corrosion of plain steel, bronze or stainless steel construction should be used. Other details to be considered are pipe sizes and filter dimensions, provisions for automatic cleaning and dumping, and available current characteristics where motor operation is to be used.

DESCALING SYSTEMS

On descaling water systems, where the average operating pressure is 800 lb. per sq. in., mill scale and other dirt which reach the nozzles produce severe abrasion at such high velocities. The consequent cutting and enlargement of the orifices result in wasteful consumption of water which is expensive to pump at these high pressures. To overcome such excessive wear to nozzles and pumps and also to prevent nozzle clogging, adequate straining is essential.

Because of high sludge loads and abrasive action, backwash filters are usually employed for descaling services. Shown in Figure 3 is a typical installation of a backwash type filter installed on the suction side of a high pressure descaling pump which delivers water to the spray nozzles at 1000 lb. per sq. in. The filter has a cartridge 16 in. in diameter by 32 in. long with .005 in. spacing and handles 800 gal. per min. continuously.

Figure 4 shows a battery of four backwash type filters installed on a 54 in. hot strip mill to strain water for descaling sprays and also cooling water for furnace skids, etc. The four units have a combined normal capacity of 10,560 gal. per min. at a pressure drop of 3 to 4 lb. per sq. in. During emergency periods flow can be doubled with increased pressure drop of 6 to 8 lb. per sq. in. These filters, each having a free area of 627 sq. in., are fully automatic. Each is equipped with a motor backwash pump and a hydraulically operated sludge blow-off valve arranged to open at pre-determined intervals.

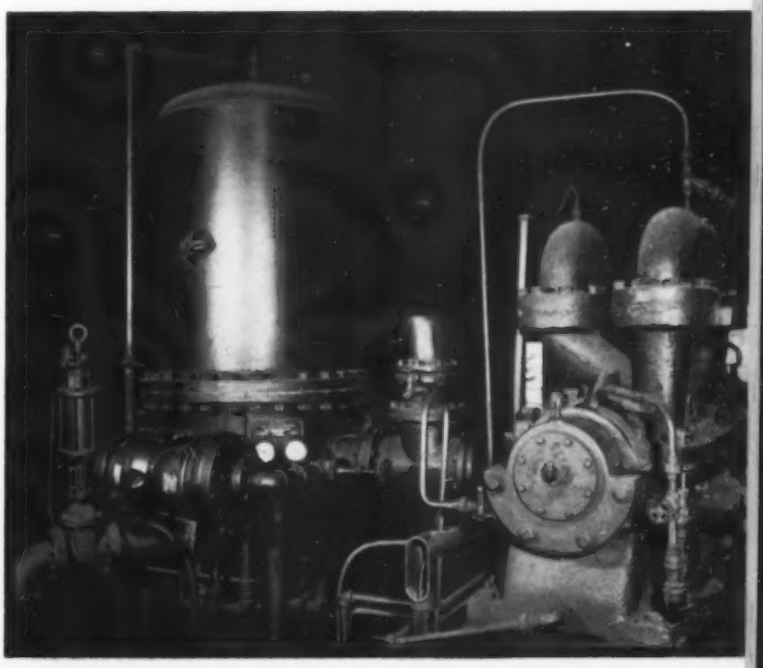
On this particular job, temperature control was an important consideration. Although an abundant supply of clean water was readily available, this company finds it less costly to recirculate and filter the water than to constantly heat up a fresh supply to the required temperature.

ROLL BODY COOLANT SYSTEMS

For the same reasons applying to their use on descaling water, backwash filters are most generally used for cold roll body coolant. Shown in Figure 5 is a backwash type filter installed on a cold reversing mill to strain a coolant solution consisting of 94 per cent water and 6 per cent soluble mineral oil. The filter is built to .006 in. spacing with a free area of 75 sq. in., and has a capacity of 231 gal. per min. at a 3 lb. pressure drop, or 347 gal. per min. at a 4 lb. pressure drop. Because the backwash used to clean the filter element is not discharged to waste but is returned to the system, there is no loss of soluble oil or water.

The system is supplied by two 200 gal. per min. centrifugal pumps. One of these is a standby which is started by a pressure control switch when the pressure falls below the normal 30 lb. per sq. in. operating pressure. The coolant returns by gravity to the baffled inlet compartment of a 4000 gal. storage tank where most of the floating sludge consisting of rags, waste, wood splinters from guides, felt nap from wipers, etc., are trapped and skimmed off. The small steel particles and other suspended sludge are separated from the coolant by the filter and removed from the system. Filters for

Figure 3—Typical installation of backwash type filter installed on suction side of 1000 lb. pressure descaling pump.



this service must be large enough to handle the full capacity of both pumps for short periods. Relief or by-pass valves cannot be used to relieve the load on the filter during such periods because dirt which might pass through the relief valve would be rolled into the strip and mar the highly polished work roll surface. A differential pressure switch is installed across the filter which operates a warning signal when an excessive pressure drop is reached, indicating that the sludge should be drained from the sump.

OTHER WATER SYSTEMS

Because most river sources of steel mill water contain sand and other abrasive suspended particles, particularly at flood stages, and because most fluid handling systems are inevitably contaminated with mill scale and dirt, the removal of these solids is essential to the proper functioning of working parts. For water lubricated bearings, the removal of all solid particles larger than the water film thickness lengthens bearing life, prevents scoring of roll necks, reduces the frequency of resetting rolls to compensate for roll neck and bearing wear, and permits rolling more accurately to gauge.

Similarly, the many small tubes of heat exchangers quickly lose their efficiency if silt is allowed to accumulate. Valves cylinders and working parts of hydraulic systems wear excessively when exposed to damaging solid particles. Here, as in the cases of descaling and roll body coolant systems, strainers of proportionate size are extensively used. Except for the smaller and lighter of these services, backwash filters are usually specified.

LUBRICATING SYSTEMS

For the adequate protection of costly oil type roll neck bearings, gear reducers, pinion stands and motor bearings, positive filtration of the full flow of lubricating oil is absolutely essential at all times. For this purpose, continuously cleanable filters, usually of the "edge" type, are installed as standard equipment in the centralized lubricating systems on the majority of modern strip mills. Thus all working parts served by the system are protected not only against stray solid particles, but, in the event of the failure of one bearing, the pieces of metal from the damaged bearing are stopped by the filter and removed from the system before reaching any of the other bearings.

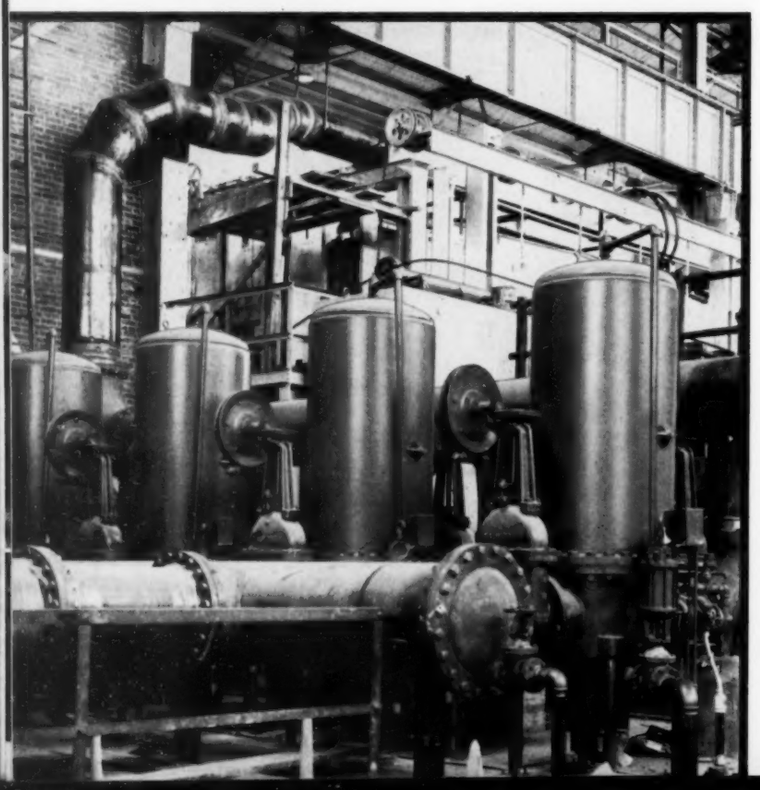
Typical of the most modern methods of lubrication is that of one 80 in. hot strip mill where four separate centralized recirculating systems lubricate the gear drives (gears and bearings), the pinion stand gears and bearings, the oil type back-up roll bearings, and the bearings of large mill drive motors and generator sets. Figure 6 shows the motor driven edge type filter on system No. 1. Similar self-cleaning filters are installed on the other three systems. Operating data are as follows:

System	Filter capacity, gal. per min.	Viscosity, S.S.U. at 100 degrees F.	Pressure drop, lb. per sq. in.
No. 1—Gear reducers....	435	1750	3–4
No. 2—Pinion stands....	580	2400	3
No. 3—Oil bearings.....	400	2400	5
No. 4—Motor bearings...	100	320	3

As further protection to the back-up roll oil bearings, there is installed on each side of the eleven mill housings a small manually operated edge type filter to remove any pipe scale and other solids which may originate within the system.

Further clarification of the oil and water removal for systems No. 1, 2 and 3 are accomplished by two 1000 gal. per hr. centrifugal purifiers, piped so that one or both can be used on any of these systems. System No. 4 has a similar centrifugal purifier of 300 gal. per hr. capacity.

Figure 4—This battery of four backwash type filters strains water for descaling, furnace cooling, etc., on a 54 in. hot strip mill.



FUEL SYSTEMS AND MISCELLANEOUS SERVICES

The effect of dirt in fuel oil lines is to clog or damage burner nozzles, instruments and controls. In addition to foreign substances, congealed lumps also form, especially in such heavy oils as bunker C. To protect fuel burning equipment against damage or stoppage, it is most important that all solids large enough to cause trouble be removed. Here again, the trend is to the use of filters which are continuously cleanable without interruption of the fluid flow. Fully automatic motor driven units are rapidly becoming universally adopted for all but the smallest capacity requirements.

Typical of the obstacles which must often be overcome in successfully engineering a filter to a difficult application is the experience of one company which decided to use fuel tar to fire open hearth furnaces. Refractory lime and other solids were present in such quantities as to not only clog the burners, but 3 and 4 in. pipe lines were quickly plugged so that it was necessary to frequently remove, clean and replace them. The only solution was to remove the solids which caused the

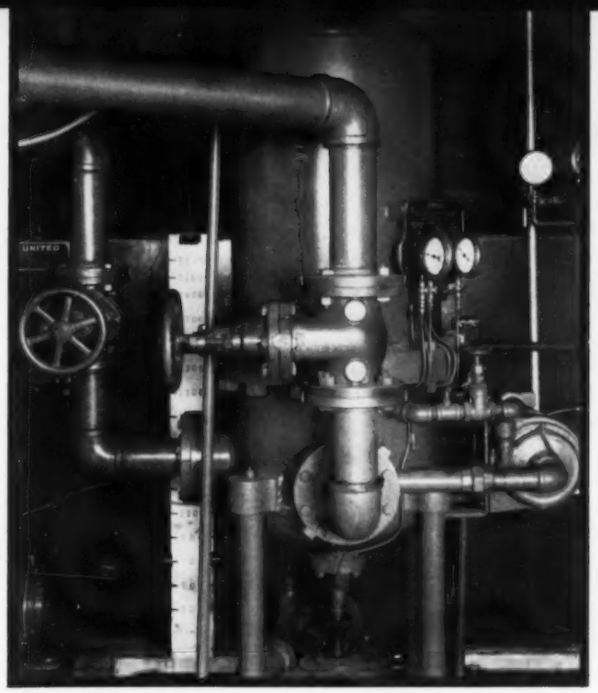


Figure 5—This backwash type filter, installed on a cold reversing mill, strains a coolant solution of 94 per cent water, 6 per cent soluble mineral oil.

trouble, but the service seemed hopelessly severe for any type of self-cleaning filter.

A small edge type filter with .006 in. spacing was placed in the line on trial. After 15 min. of operation it became plugged to the point where it would not pass the required flow of fuel. Another unit with .012 in. spacing was then tried. This one ran for several days and enough information was obtained from the test to permit the installation of full size filters on the main line. A primary filter with .031 in. spacing, motor operated for continuous cleaning, was installed to remove most of the coarser sludge. Beyond this filter, a similar unit but with .015 in. spacing was placed in series for the second stage. The results were so good that they were able to reduce the size of burner nozzles for higher efficiency, and for the first time it was possible to install meters to measure the amount of tar used. A number of similar installations were made at other plants of this company with the result that burner clogging and fluctuation of the flame were entirely eliminated. Thermostatic controls and other instruments which could never be used before are now used without difficulty.

In addition to the more important steel mill filter applications described above, numerous others exist, a few of which can be briefly mentioned here. On quenching oil systems, the efficiency of heat exchangers used to cool the oil is greatly increased and periods between tube cleanings lengthened if a filter is installed to remove the scale and other dirt which otherwise accumulate on the tubes. Common practice is to place the filter on the suction side of the pump which recirculates oil through the quenching tanks and coolers.

The phenol departments of various plants are now successfully using filters of the backwash type with spacings of .005 in. and .006 in. to handle hot ammonia liquor at temperatures up to 212 degrees F. The solids removed consist of pitch, tar, coke particles, etc., which would otherwise clog the spray nozzles on the cooling tower. Many types of filters were tried out on this very difficult job before it was successfully handled.

Recent experimental tests were run on a strip cleaner line with equipment consisting of a pump and a backwash filter built to .003 in. spacing. The alkali solution was pumped from the bottom of the vat through the filter and back into the top of the vat. The amount of sludge removed proved that such a system can be used to remove the dirt from the vats continually, thus making the liquid last indefinitely, eliminating shut downs and assuring a cleaner product.

It is important to remember that filters of the types used in the steel industry must be individually engineered to the particular job. Required capacity, degree of filtration, spacing, viscosity, amount and nature of solids to be removed, maximum allowable pressure drop, pipe size and space limitations are among the many factors which must be considered.

The mistake is often made of deciding upon a spacing much finer than is actually required for adequate protection of the equipment in question with the result that a heavy premium is paid for the removal of solids which would do no harm if allowed to pass. Not only does finer spacing require a larger filter to provide the same free area, but a greater amount of free area is required to handle the greater proportion of sludge removed.

Some questions such as the maximum allowable velocity through the openings of the filter element involve judgment factors which can only be based on experience. It is here that the engineers of progressive filter manufacturers can be of great assistance. Data based on hundreds of successful installations and classified by type of service, reduce dependence upon judgment to a minimum. Whenever a filtration problem is being considered, it is always best to consult a filter engineer. His experience is a virtual necessity in determining specifications. He is a specialist in the complex science of removing solids from fluids.

Figure 6—Motor driven edge type filters are used in the centralized recirculating oil systems which lubricate units of a modern 80 in. strip mill.

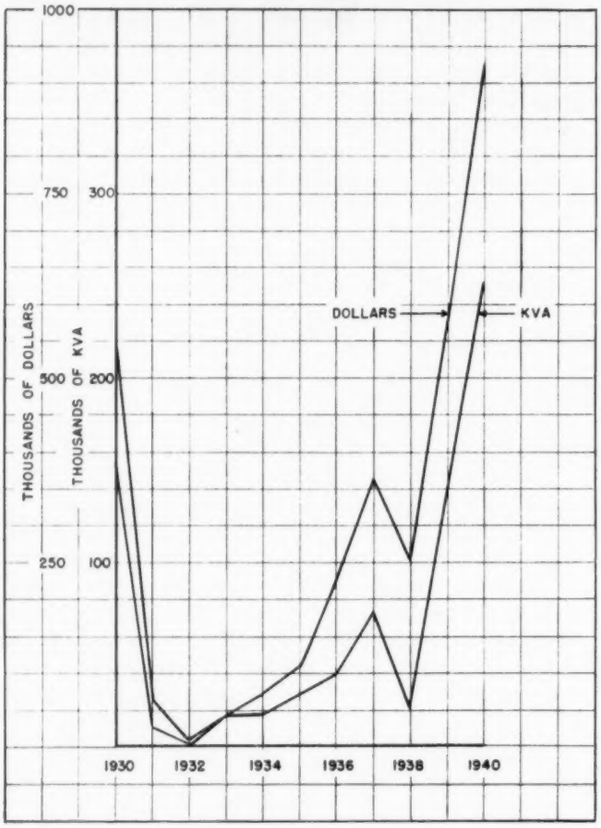


Figure 1—Curves of yearly sales of arc furnace transformers indicate the rapid expansion in recent years.

Fundamental

▲ THE purpose of this paper is to present the fundamentals involved in a design of a power distribution system to adequately serve arc furnace loads. The material presented here is not new to certain groups in the power industry, but it has been prepared especially for engineers in the electro-chemical and electro-metallurgical industries who normally are not acquainted with the power distribution problems associated with loads of the arc-furnace type.

Before analyzing the arc-furnace load, and in order to provide a background for the discussion to follow, it is pertinent to review briefly: (1) the flicker problem, and (2) methods of controlling voltage on a distribution system.

The problems of electric utility companies in distributing their product have become increasingly severe. The principal reasons for this are threefold:

1. Many new loads, formerly non-existent or rare, are rapidly developing which, because of their highly fluctuating nature, and also their low power factor, have made it difficult to maintain satisfactory delivered voltage.

2. Other loads, particularly lighting (both incandescent and gaseous tube) and heating loads have grown rapidly and are especially dependent on good voltage for satisfactory performance.

3. Power consumers have become more voltage and service-conscious.

The arc furnace is a good example of a highly fluctuating load which has grown rapidly in recent years. This is borne out by the curves of Figure 1 which show total sales of arc furnace transformers (in both dollars and kva.) year by year in this country during the last ten years. The growth has been tremendous during the last two years. With present industrial activity there is every indication that this trend will continue, carrying with it the increase in voltage control problems on the power distribution system.

Usually the device which produces the devastating effects on delivered voltage is not the device which suffers from such effects. This accentuates the problem.

In designing a distribution system to deliver adequate voltage service, proper average voltage levels must be maintained to insure that utilization equipment will deliver rated output and operate at optimum efficiency. Also, it must be designed so that sudden changes in voltage (flicker) are limited to an unobjectionable value. This latter problem in design is currently the most prevalent and the most difficult to solve.

ALLOWABLE FLICKER TOLERANCES FOR LIGHTING

By far, the greatest sufferer from sudden changes in voltage is lighting, both incandescent and gaseous tube. Considerable has been written on the subject of objectionable flicker and in some cases the findings have been based upon a substantial amount of basic research. Many operating companies have established allowable flicker tolerances, based largely on complaint experience.

The degree to which flicker may be objectionable is dependent on the magnitude of the voltage dip or rise, the time required for the change, the time duration of the change, and the frequency with which such changes occur. In considering frequency of occurrence, flicker troubles immediately break down into two forms—cyclic and non-cyclic.

Infrequent voltage dips of considerable magnitude may not be objectionable, whereas cyclic variations of barely perceptible magnitude are. Figure 2 shows the threshold of perceptibility for cyclic variations based upon laboratory tests. Curves showing the threshold of objectionable cyclic flicker would be similar to these, but more tolerant as dictated by experience and practical considerations. Figure 3 shows such a curve which is used by many engineers as a criterion for design.

Less data are available on non-cyclic flicker. A sudden voltage change may take place in less than a cycle of time and easily be noticeable, or it may take

Considerations in Supplying

POWER to ARC FURNACES

By F. M. Starr and O. B. Falls

CENTRAL STATION ENGINEERING DEPT.

GENERAL ELECTRIC CO., Schenectady, N. Y.

Presented before Joint Meeting A. I. S. E. and A. I. E. E. at Canton, Ohio, May 27, 1941

place over a long enough period as to be unnoticeable. Also, a voltage dip may be easily noticeable, but so infrequent as to be unobjectionable. Under these conditions it is difficult to prescribe tolerances. One eastern utility, however, prescribes, as a design criterion, the data set forth in Table I.

The duration of an abrupt change in voltage is also important in evaluating its seriousness. The report of the Utilities Coördinated Research, Inc., on the subject of flicker has the following to say:

"As might be expected, the amount of abrupt voltage drop necessary to cause perceptible flicker varies somewhat with the duration of the drop. It was found that, although a voltage transient of about 5 cycles duration has maximum effectiveness in producing perceptible flicker, there is comparatively little difference in this effect for periods ranging from 3 to 15 cycles."

In considering allowable voltage dips, in addition to the annoyance tolerance, there is the further consideration of proper performance of the lamps. Incandescent lamps will function over wide ranges of voltage, although they will not do so efficiently. The fluorescent lamp must operate within a voltage range of 110–125 volts. Voltages below 110 may cause unsatisfactory starting. Voltages above 125 may burn out the auxiliary and impair the quality of illumination. Mercury lamps are particularly sensitive to voltage changes, particularly sudden ones. The newer lamps have better characteristics than the old ones, however, because of improved ballasts. Modern mercury vapor lamps will withstand

TABLE I

Voltage Flicker Limits for Distribution System

	Volts on 115 volt base		
	Infrequent*	Frequent	Extremely frequent
A. On a substation bus feeding only power lines	6	4	3
B. On a power line primary circuit the entire output of which is not taken by one customer and read at the customer's premises	8	6	4
C. On a power line the entire output of which is taken by one customer and read at the customer's premises	No limit	No limit	No limit
D. On a substation bus feeding distribution circuits (lighting) and on distribution circuit primary circuits	6	3	2

*Infrequent flicker shall include fluctuations occurring 6 times or less in 24 hours, but not more than once between 6:00 P.M. and midnight. This provision is intended to cover apparatus, such as motor generators, fans, pumps, etc., which normally runs continuously throughout the working day.

Frequent flicker shall include fluctuations occurring not oftener than 3 times per hour, except that between 6:00 P.M. and midnight they shall not occur more than once per hour. This provision is intended to cover apparatus such as machine tools, electric furnaces, etc., which is started and stopped periodically throughout the working day.

Extremely frequent flicker shall include all fluctuations occurring more frequently than the above. This provision is intended to cover such apparatus as flashing signs, welders, gravel pit hoists, and certain electric furnaces, which are stopped and started frequently and repeatedly or rapidly loaded and unloaded during normal use.

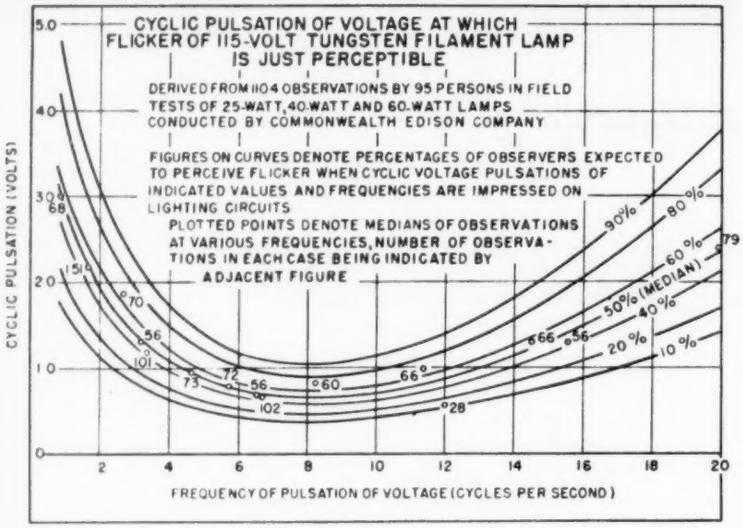

CYCLIC PULSATION OF VOLTAGE AT WHICH FLICKER OF 115-VOLT TUNGSTEN FILAMENT LAMP IS JUST PERCEPTIBLE
DERIVED FROM 1104 OBSERVATIONS BY 95 PERSONS IN FIELD TESTS OF 25-WATT, 40-WATT AND 60-WATT LAMPS CONDUCTED BY COMMONWEALTH EDISON COMPANY
FIGURES ON CURVES DENOTE PERCENTAGES OF OBSERVERS EXPECTED TO PERCEIVE FLICKER WHEN CYCLIC VOLTAGE PULSATIONS OF INDICATED VALUES AND FREQUENCIES ARE IMPRESSED ON LIGHTING CIRCUITS
PLOTTED POINTS DENOTE MEDIANS OF OBSERVATIONS AT VARIOUS FREQUENCIES, NUMBER OF OBSERVATIONS IN EACH CASE BEING INDICATED BY ADJACENT FIGURE
90%
80%
60%
50% (MEDIAN)
40%
20%
10%
CYCLIC PULSATION (VOLTS)
FREQUENCY OF PULSATION OF VOLTAGE (CYCLES PER SECOND)

Figure 2 (above)—Curves showing the threshold of perceptibility for cyclic voltage fluctuation.

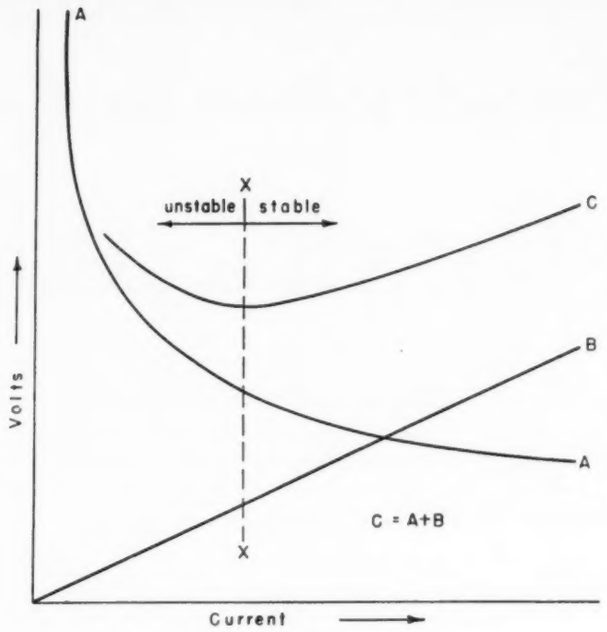


Figure 4 (right)—Chart indicating stability of the electric arc under varying conditions.

a voltage change of perhaps 10 volts, but the older ones may give unsatisfactory performance with voltage dips of as much as 5 volts.

METHODS OF VOLTAGE CONTROL

The term voltage control on a distribution system is a broad one. It implies the maintenance of proper voltage levels to all customers 24 hours a day with normal changes in load, and it also implies the minimizing of flicker accompanying highly fluctuating loads.

Regulators—induction and step—are used to maintain adequate voltage levels with normal changes in load. Regulators, however, particularly step regulators, will not correct for voltage dips accompanying highly fluctuating loads because they are not fast enough.

One of the most useful devices in correcting for highly fluctuating loads is the series capacitor. A series capacitor produces a voltage rise at its point of location proportional to the load current flowing through it. This voltage rise is instantaneous and always accompanies a sudden change of load. The series capacitor has its limitations, however, and, when applied, must be applied with considerable care.

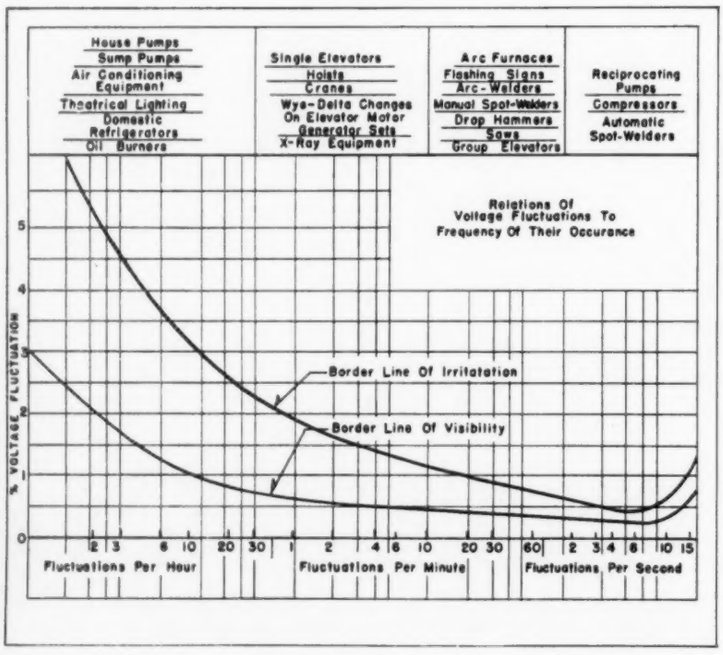
A synchronous condenser, located close to a highly fluctuating load will tend to absorb the fluctuations and keep them from the other parts of the system. This is especially true if the varying load is highly reactive.

A motor-generator set, with or without a flywheel, depending on load factor, duty cycles, etc., as a separate and individual power supply for the fluctuating load, is an effective method of keeping flicker off the distribution system.

However, rotating machinery is usually not an economical solution to flicker troubles unless the load is fairly large, since rotating machinery—either synchronous condensers or motor-generating sets—have a high cost per kva. in small sizes.

Perhaps one of the most effective ways of improving voltage troubles on a system is to reduce the inherent impedance in the system, especially that part of the system serving the troublesome load. This procedure not only minimizes flicker troubles, but also reduces normal voltage drops, thus reducing the size and range of regulators required for normal regulation.

Figure 3—Many engineers use these curves of cyclic voltage fluctuation as a basis of design to avoid objectionable flicker.



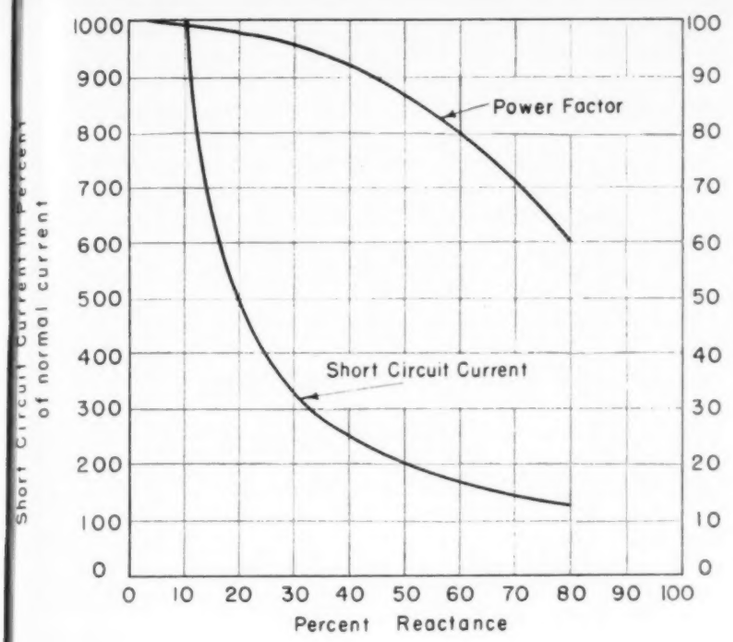

Short Circuit Current in Percent of normal current
Power Factor
Short Circuit Current
Percent Reactance
0 10 20 30 40 50 60 70 80 90 100
0 100 200 300 400 500 600 700 800 900 1000
0 10 20 30 40 50 60 70 80 90 100

Figure 5 (left)—Curves showing effect of reactance upon power factor and short circuit current.

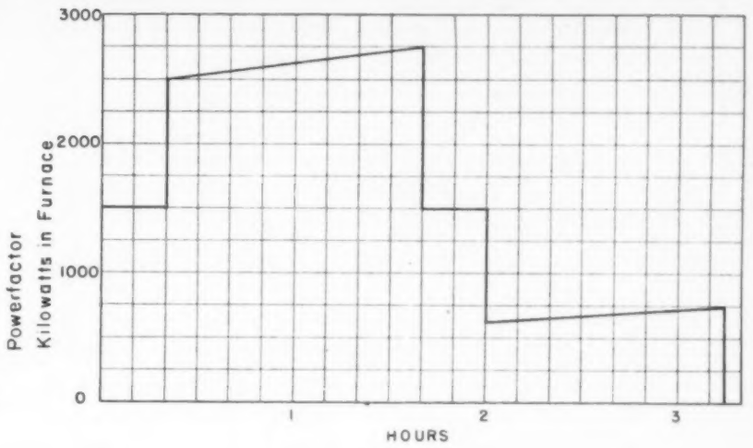


Figure 6 (above)—Graphical presentation of power input to furnace during a typical heat.

These several methods of voltage control, as they apply to arc furnace loads, are described in more detail below.

However, in order to arrive at any conclusion as to the effectiveness of these various methods of correcting or minimizing the difficulties encountered, it is pertinent to first examine the nature of arc furnace loads.

NATURE OF ARC FURNACE LOAD

The satisfactory and efficient operation of an arc furnace depends on the stability of the arc. The condition for stability in an electric circuit is met only when the volt ampere characteristic of the circuit shows an increase in voltage simultaneously with an increase in current; *i.e.*, a positive characteristic. This condition is not obtained by an arc. (See Figure 4, curve A.) Therefore, the arc (having a negative volt-ampere characteristic) is not independently a stable form of electric circuit.

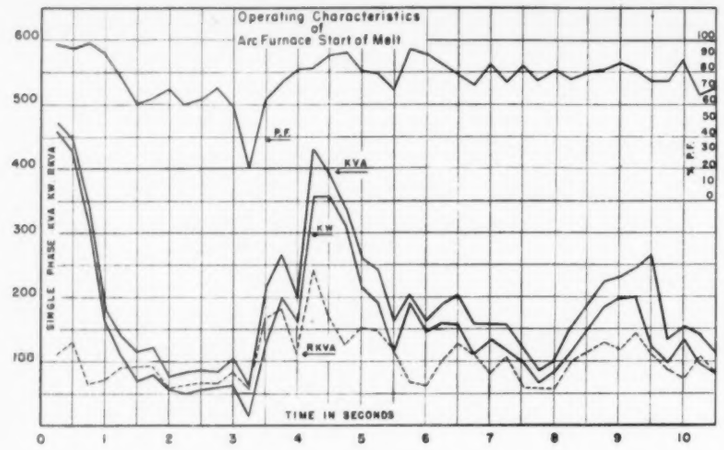
Since the arc furnace circuit in practice is operated from a source of constant voltage, it is necessary that there be in series with the arc an element which has a positive volt-ampere characteristic such that the volt-ampere characteristic of the circuit taken as a whole will conform to the requirements for stability. Curve B, Figure 4 represents the volt-ampere characteristic of a typical stabilizing element, and curve C shows the result of the arc and stabilizing element in series. It is to be noted that there is a value of current and voltage for this given length of arc which marks the limit of stability. The reactance and resistance which may compose the stabilizing element, and the supply voltage, are fixed values. Thus, stable operation to the degree required is obtained by adjusting the length of the arc in order to maintain the current at some value higher than the critical value—designated by line *XX*, Figure 4. These variations in current, brought about by a change in arc length, are of importance, as discussed below, when considering voltage regulation of the power supply system.

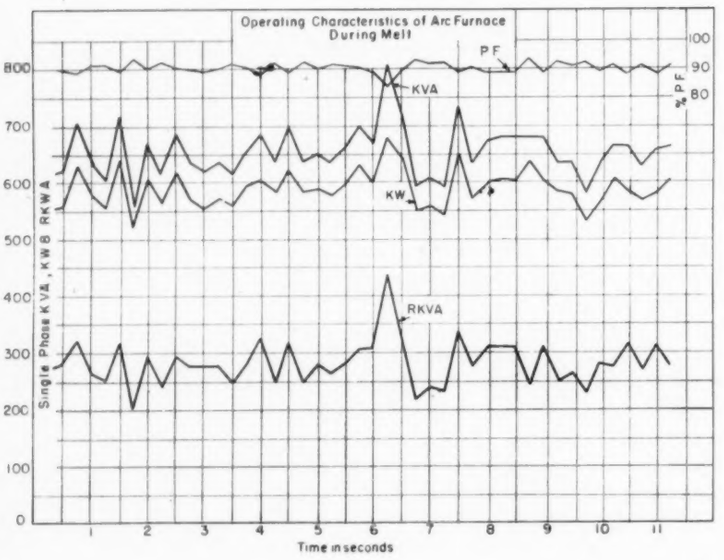
The stabilizing element for an arc can be either resistance, reactance or a combination of the two in any ratio. In general, however, reactance is used for the major portion of the stabilizing element merely as a matter of economy. The use of reactance, however, tends to lower the power factor of the load, and for this reason, has an adverse effect on the regulation of power supply lines. Conversely, however, including reactance in the circuit will reduce the magnitude of the current swings on the power supply system during the early part of the furnace melt.

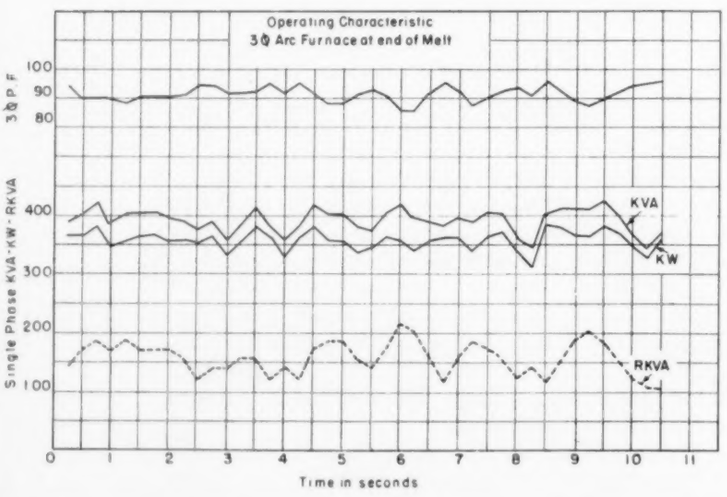
Assuming a series reactance having a straight line characteristic, Figure 5 shows the effect on power factor and short circuit current for various percentage values of reactance. For example, if there is only 10 per cent reactance in the circuit, the short circuit current will be 10 times normal and the power factor 0.995; whereas, if there is 50 per cent reactance present, the short circuit current will be only 2 times normal, but the power factor will be down to 0.866.

Ideal operation of an arc furnace is a combination of a high melting rate with low total energy input to the furnace circuit at a high average power factor. The degree to which this ideal is approached, as well as the effect of the furnace operation on the power supply system is dependent in part on the care exercised in selecting operating voltages and reactances, and in part on the skill of the operator.

The rate at which the furnace charge is melted down is a function only of the heat receptivity of the metal, if it is assumed that sufficient energy can be made available. Heat receptivity of the metal, however, decreases with an increase in temperature. Therefore, if a constant rate of energy input to the furnace is maintained,







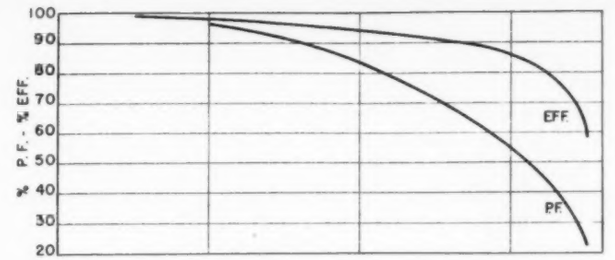
there will be an excess of energy available after the charge begins to melt down. This excess energy is expended in flow to the surrounding atmosphere and in melting the refractory. The life of the refractory, particularly the roof, is longer and the total energy input per melt is smaller, the less the power input exceeds the normal heat receptivity value at any stage of the melt. The rate at which energy is fed into the furnace is controlled by the furnace transformer voltage. Therefore, the ideal melting rate can be approached only when a multiplicity of voltages are available.

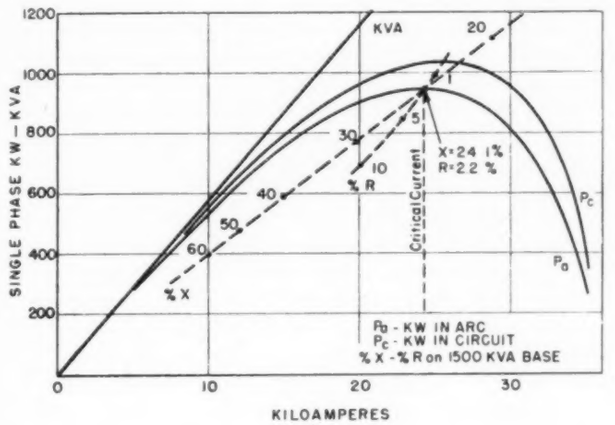
Theoretically, the voltage held at the start of the melt should be high to give a high rate of energy input to match the high heat receptivity of the cold charge. However, for a given value of reactance, the normal current swings (not the short circuits) reflected on the power supply system are directly proportional to the voltage held on the furnace. For this reason it is customary to hold a relatively low voltage for the early part of the melt until the charge becomes molten. This condition may be held for from 15 minutes to 30 minutes after the start of the furnace, at the end of which time a higher voltage may be applied in order to increase the rate of energy input to the furnace. As the furnace charge becomes molten, and the heat receptivity of the charge decreases, the lower values of voltage may be applied in order to follow the declining characteristic of the heat receptivity of the charge. Figure 6 shows in graphic form this type of operation. The voltage to produce this type of operation might well be of the order of 100 per cent, 75 per cent and 50 per cent. During the latter part of the melting period the energy input to the furnace is equal to the rate of heat loss of the furnace. Thus, proper selection, on the part of the operator, of voltages and supplemental reactances will tend to reduce to a minimum the current swings as well as the total energy input to the furnace.

Figures 7, 8, 9—These three charts show, respectively, the widely fluctuating type of load at the start of melt *(top)*, the less violent fluctuations of the early part of the melt *(middle)*, and the rather constant conditions holding near the end of the melt *(bottom)*.

In view of the above, and considering the entire length of one melt of an arc furnace, there are several rather distinct conditions of operation obtained.

1. The start of the melt—during which time the electrodes may actually touch the charge a number of times in order to start an arc or melt-down the charge; thus placing a direct short circuit on the system. The current drawn from the system under such conditions (that is short circuit) will be limited only by the circuit impedance, including transformers, supplementary reactors, and secondary supply circuits to the furnace. Since the supply system impedance, transformer impedance and secondary circuit impedance are all essentially constant, the most convenient method of placing

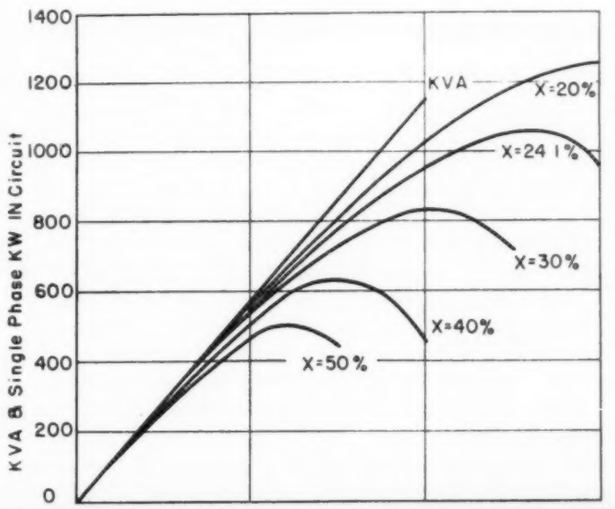




Figures 10, 11 (above)—Curves showing the operating characteristics in kilo-amperes of 6-ton furnace referred to in connection with Figures 7, 8 and 9.

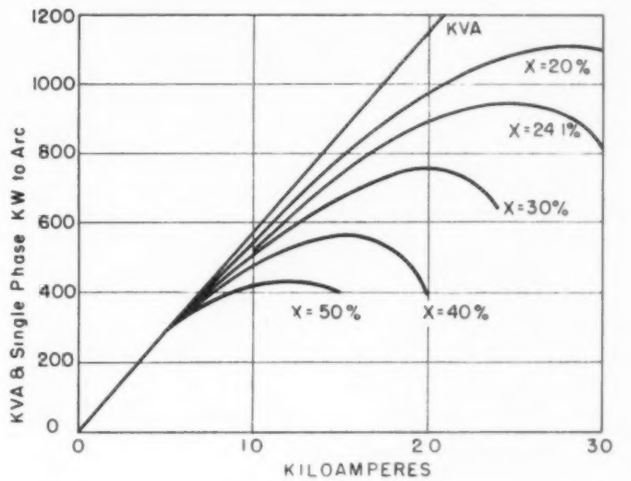
•

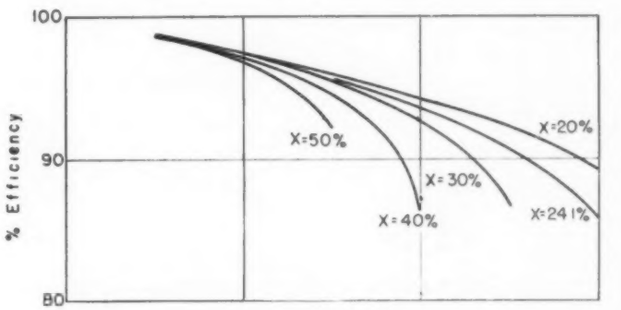
Figures 12, 13, 14, 15 (below and right)—Curves showing fully developed set of operating characteristics for various reactance values, assuming the resistance to remain constant at 2.2 per cent.

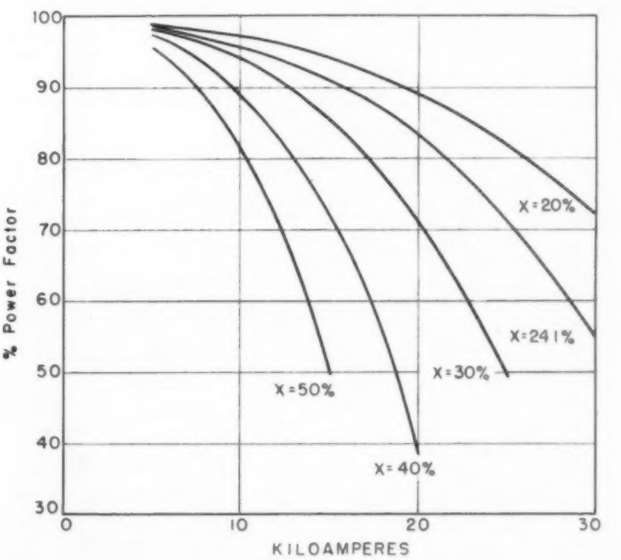


additional impedance in the circuit to reduce the short circuit current peaks is to use supplementary reactors. The effect on furnace operating characteristics of adding reactance to the furnace circuit will be discussed in more detail later.

Also, during the start of the melt, the condition of the charge is such that wide variations and swings of current are obtained other than due to short circuits when the electrodes touch the cold charge. The magnitudes of these swings may be minimized by using a







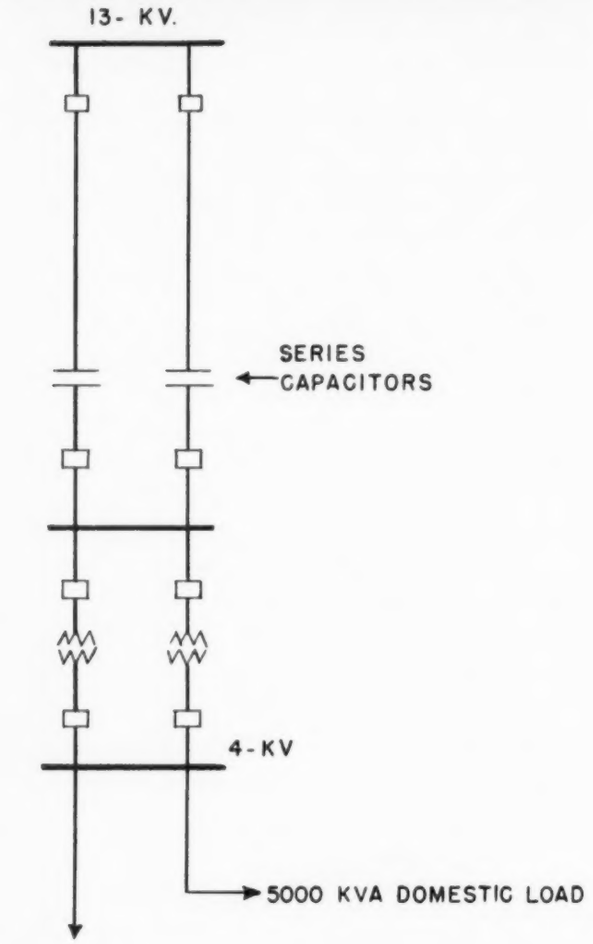


Figure 16 (top)—System in which 500 kva. arc furnace and 5000 kva. domestic load are connected on same bus.

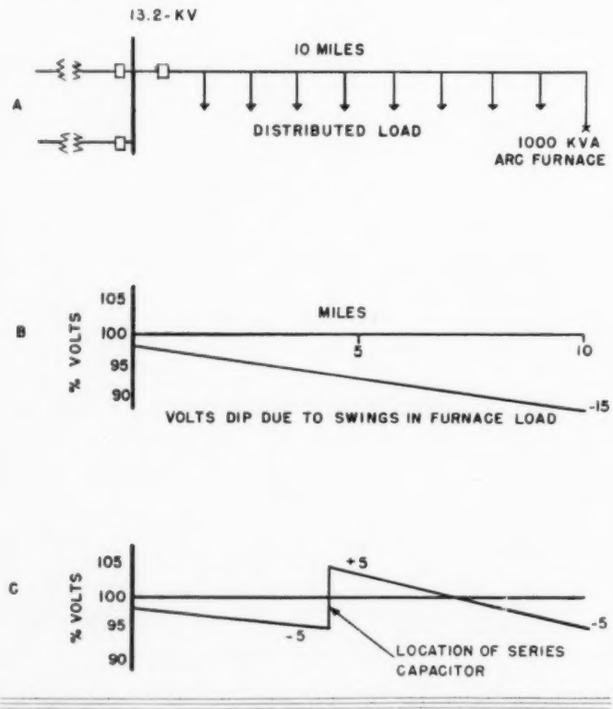


Figure 17 (bottom)—Graphical presentation of results of installing a series capacitor in system.

reduced voltage on the furnace as pointed out above and indicated in Figure 6. Figure 7 indicates the widely fluctuating type of load obtained during the start of the melt. This is a reproduction of the envelop of an actual oscillogram covering a 10 second interval taken approximately 5 minutes after the first arc was struck in the furnace. It should be noted from these curves that the magnitude of the kw. swings is considerably greater than the reactive kva. swings. Inspection of the oscillograms from which this chart is obtained, as well as a number of other oscillograms indicates that the major portion of furnace load swings in this case is kw. rather than reactive kva.

2. During the early part of the melt, before the charge has become completely molten, or at times when additional quantities of cold material are added to the furnace, load swings will continue to be obtained. The swings, however, will not be as violent nor as frequent as during the start of the melt. Figure 8 is indicative of this condition of operation. These curves are similar to those of Figure 7, but cover approximately 10 seconds at about one hour after the initial start of the furnace. Under the conditions indicated in Figure 8, when the fluctuations are not as great nor as frequent, it is possible to use a higher voltage on the furnace, and thus force more energy into the charge.

3. Toward the end of the melt, after the charge has become completely molten, the load is quite constant and only minor fluctuations are obtained. Refer to Figure 9 which is similar to Figure 7 and 8, except that it is taken a few minutes before the end of a 4 hour run.

Figures 7, 8 and 9 were taken at the different times, as indicated above, during the same run of a 6-ton Heroult furnace. Comparison of the curves shown in these three figures shows that the greatest difficulty from fluctuating loads is encountered during only a comparatively short period of the total time required for a complete run of the furnace.

Reactors supplied with furnace transformers usually have a number of taps to permit selection of the optimum value of total impedance in the circuit, from the standpoint of optimum furnace operation. These taps, or additional taps, may be used to insert more reactance in the circuit during the start of the melt than would normally be used during the melting-down period.

The use of reactance, while limiting short circuit currents, presents several adverse effects in the normal furnace operation. As pointed out above, it lowers the power factor of the furnace load as reflected back in the system. Low power factors are undesirable due to the fact that the average circuit supplying furnace loads has a ratio of circuit X/R of the order of 2/1. Thus, each reactive kva. will cause approximately twice as much drop as each kw.

Figure 10 and 11 show the operating characteristics,

in terms of furnace-kiloamperes, of the 6-ton Heroult furnace, referred to in connection with Figures 7, 8 and 9. Power is supplied to this furnace over a 10-kv. circuit approximately 6 miles long. On a 1500-kva., 10-kv. base, the total reactance in the circuit is approximately 24 per cent, and the total resistance is approximately 2.2 per cent. With these values, the maximum possible power input to the arc (Figure 11), is approximately 940 kw. per phase. Similarly, the maximum possible power input to the circuit is approximately 1030 kw. per phase, the difference representing the losses in the circuit.

Assume now, the resistance in the circuit to be held constant and the reactance varied, such as might be done by changing a tap on a supplementary reactor in the supply circuit or in the primary of the furnace transformer. The dotted curve marked per cent X, represents the locus of the point of maximum possible power in the arc. Similarly, the dotted curve marked per cent R represents the locus of the points of maximum possible power in the arc if the reactance is held constant and the resistance varied.

Figures 10 and 11, with the exception of the dotted curve, show the operating characteristics of this particular furnace circuit for one set of circuit constants. Figures 12 to 15 inclusive, show a fully developed set of operating characteristics for the various values per cent X, shown on the dotted curve of Figure 11, assuming the per cent R to remain constant at 2.2 per cent.

Close study of these curves will reveal some interesting facts as to the effects on furnace performance of inserting various values of reactance in the circuit. For the sake of brevity, only the following are mentioned; however, such a set of curves can be of immeasurable assistance in analyzing furnace performance.

1. Increasing the reactance decreases the maximum power available in the arc and in the circuit, as well as the critical currents of the circuit. However, since the critical current of some given circuit may be greater than the maximum current required, this may not be detrimental to efficient furnace operation.

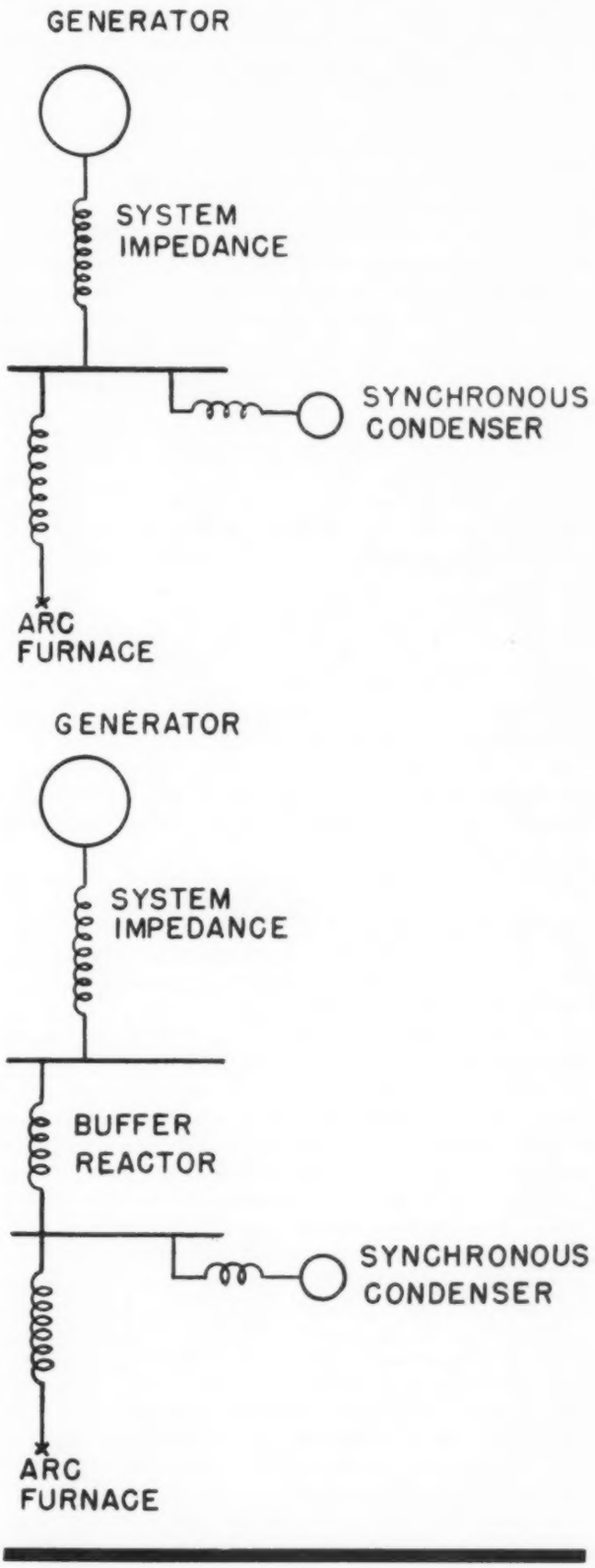
2. Increasing the reactance may decrease or increase the power factor and efficiency of the circuit. For example, for any given value of current the power factor and efficiency of the circuit will both decrease as the amount of reactance is increased. If, however, as recommended for the start of the furnace, the circuit is operated at say a voltage which will give 10,000 amperes instead of a voltage which would give 20,000 amperes, and 50 per cent X used instead of 30 per cent X, the power factor and efficiency will be increased.

3. In any case, regardless of the amount of reactance in the circuit, if the furnace is operated at a value of current slightly less than the critical current, the power factor will be of the order of 80 per cent to 85 per cent, and the efficiency will be of the order of 90 per cent to 95 per cent. Operation at a value slightly less than the critical current is considered good operating practice.

One way in which the chart could be used to advantage could be as illustrated below.

Figures 7, 8 and 9 indicate that the maximum power required in the circuit is approximately 600 kw. per phase. In this case, the 24.1 per cent X actually in the circuit may be of a satisfactory value from an arc

Figure 18—A buffer reactor, to increase system reactance back of furnace bus, may be necessary to substantially reduce voltage flicker.



stability standpoint. However, 40 per cent X could be used and still obtain sufficient power in the circuit (Figure 12) if arc stability could be maintained. The higher value of reactance would reduce the short circuit current swings at the start of the melt to approximately 60 per cent of the value obtained with 24.1 per cent reactance, but would cause the power factor at the critical current to drop from approximately 91.5 per cent to approximately 70 per cent and the efficiency at the critical current to drop from 94.5 per cent to 93.5 per cent.

SIZES OF FURNACE LOADS

A review of installations of arc furnaces during the past 10 years indicates that furnaces range in size from approximately 100 kva. to 15,000 kva. From present indications, this latter is apparently the maximum size for economical operation. The average rating of existing furnace installations is approximately 5000 kva. These furnaces are supplied power by circuits rated from 2.3 kv. to 70 kv. with the majority in the range of 11 kv. to 22 kv. Such a review indicates that utilities may be called upon at any time to furnish power to a rather large load which, although it has a high load factor and therefore would be a profitable load to serve, presents very definite problems from the power supply standpoint.

It has been found necessary in a number of cases to attempt to determine, prior to an installation, just what effect a particular arc furnace installation will have on the power supply system. Heretofore, it was considered necessary to collect a multiplicity of data and to perform laborious calculations in order to determine these effects. Since the furnace at the beginning of the melt, when the charge is cold, acts as a direct short circuit, it is felt that one simple and conservative basis on which to start would be as follows:

Assume the system connections on which the furnace will be operated most of the time. Then determine the maximum allowable change in current to give a voltage change which is within the specified limits for the system in question. For purposes of making these calculations, it may be assumed that the frequency of fluctuation will be of the order of 6 to 10 per minute. This step would be quite simple, since the necessary information has usually already been prepared for system short circuit study. The total reactance in the circuit of arc furnaces below approximately 5000 kva. is of the order of 50 per cent at the nominal current of the furnace. If the furnace manufacturer's recommendations are available as to the amount of reactance which it is expected will be obtained in some particular installation, then this value, plus system impedance to the point of installation of the arc furnace should be used. For purposes of this discussion it will be assumed that this value is approximately 50 per cent. This means that the maximum current under a short circuit (of the furnace electrodes which may occur during the cold-melt period) will be twice the full load current of the furnace. With the above two facts, the full load rating of the furnace is determined.

Conversely, if the rating of the furnace transformer is known, it will be possible to calculate the voltage dips which will be obtained when the furnace is installed at the assumed location.

Assuming that it is desired to determine the size of furnace which can be installed at a given point, and the full load current rating of the furnace is determined as above, the maximum power input to the furnace circuit corresponding to this current is at 70.7 per cent power factor. Deducting the I^2R loss in the circuit, the furnace transformer and connections from this value of maximum power gives the maximum rate of heat development in the furnace. Thus, it is possible to determine the size of furnace which can be supplied at a given point in the power system.

This method, from one viewpoint, will indicate a furnace load smaller and from other viewpoints a furnace load larger than could actually be tolerated. For example, this method assumes that load current will increase from zero to a value corresponding to a short circuit from 6 to 10 times per minute. This may actually happen during the first few minutes of operation of the furnace; however, in general, the maximum change in load even over a period corresponding to approximately one cycle will be considerably less than this short circuit value. For this reason, a somewhat greater voltage dip might be permissible. Any increase in allowable voltage dips will give a corresponding increase in allowable load, at the assumed location. Also, if it is permissible to insert supplementary reactance at the start of the furnace, this reactance will decrease the short circuit current and therefore a larger furnace load would be allowable.

Furthermore, once this furnace load is determined, if it is assured that the furnace will be started with a

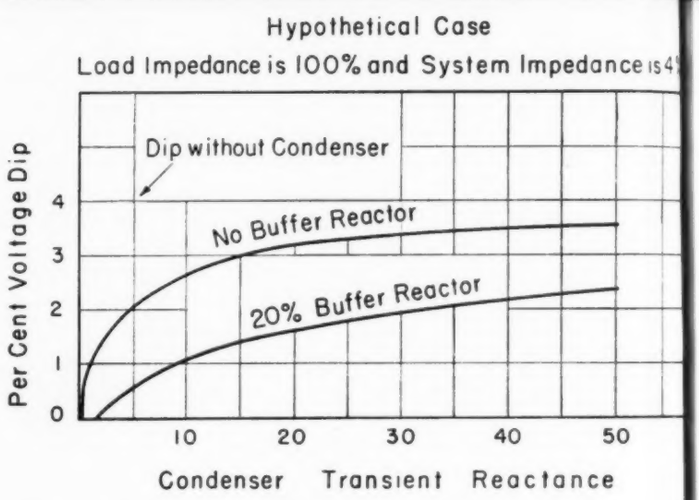
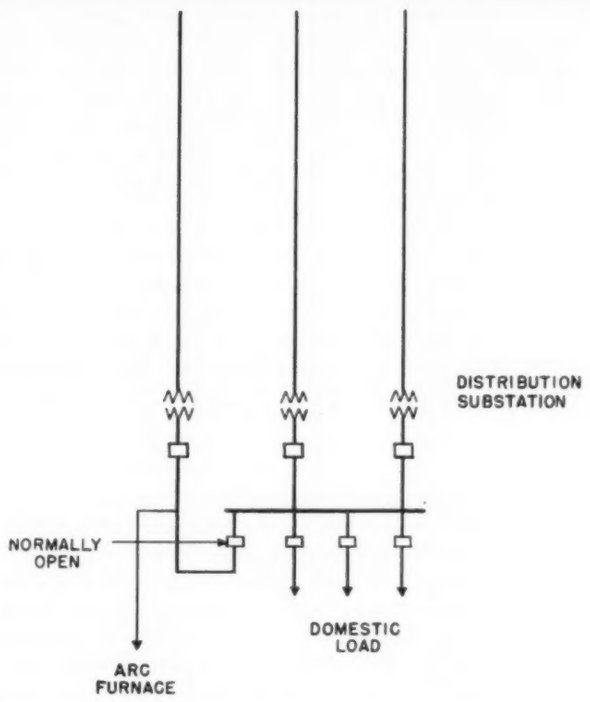


Figure 19 (above)—Curves showing how buffer reactor improves synchronous condenser's correction of fluctuations.

Figure 20 (right)—Schematic arrangement of system designed to eliminate flicker trouble.

reduced voltage, the nominal full load rating of the furnace may be increased in direct proportion to the ratio of the voltage which will be held at the time when maximum rate of energy input to the furnace is obtained to the voltage which is held at the start of the furnace. This is possible due to the fact that after the initial period of approximately 30 minutes the magnitude of load swings as well as frequency of fluctuation will decrease, and therefore a higher current demand from the supply system can be tolerated.

On the other hand, the furnace may be considered as consisting of three separate single-phase loads. Thus, during the start of the melt, when operating conditions are most severe, it is possible for any of the two phase wires to carry current with approximately zero current in the third phase wire. This constitutes essentially a single-phase condition of operation. Again, however, this condition of operation is obtained only during the first 15 to 30 minutes of operation of the furnace. On this basis, the voltage drop which would have been calculated on the basis of balanced 3-phase loads, would be approximately twice the allowable. In other words, the resulting furnace load calculated would be approximately twice as large as could be tolerated.



Giving full consideration to the above, it would appear that these various points will tend to counteract each other and thus give a reasonably accurate result.

The results obtained from the use of this method will depend a great deal on the discretion of those using it in properly taking into account the various factors involved. Its use, however, will assist in indicating the order of magnitude of furnace load allowable at any one point in the system. If results obtained are indicated to be favorable, then a more detailed study may be justified. Also, such an investigation may indicate that some form of correction will be required. If such is the case, consideration may then be given to the various methods discussed in detail below and some decision arrived at prior to the installation of the furnace as to which type of correction will be the most effective.

THE SERIES CAPACITOR

The series capacitor is perhaps suggested more frequently than any other device as a means of correcting flicker on distribution circuits. The principal reason for this is that it gives instantaneous voltage correction which is directly proportional to changes in load current. Like a regulator, the voltage rise produced by the series capacitor is all concentrated at one point. This voltage rise appears only ahead of the capacitor in the direction of power flow.

While the series capacitor has been found to be the ideal solution to many flicker problems, it has its limitations and must be applied with a great deal of care if the anticipated performance is realized. For example, a series capacitor can compensate for a specified amount of line drop, but only at a particular power factor. The compensation or voltage rise for the same current at a different power factor might be quite different.

Again, it is sometimes difficult to find a location for a series capacitor such that it will provide the necessary correction. Consider two examples:

In Figure 16 a 500 kva. arc-furnace load and a 5000 kva. domestic load are connected on the same bus. Swings in the arc-furnace load produce a 6 per cent voltage dip on the 4 kv. bus which is highly objectionable to the domestic load. Two series capacitors in the 13.2 kv. supply lines would reduce the flicker to a satisfactory value, but each would have to be good for approximately 6000 kva. of load (thermally) even though the fluctuating component is only 500 to 1000 kva. Moreover, the effects on voltage at the 4 kv. bus following a 13.2 kv. line outage would need to be studied carefully. In some cases, special switching equipment might be required to parallel the two capacitors on one circuit in the event of a sustained outage of the second.

It is probable that in cases similar to the one just described, the series capacitor would prove to be an uneconomical solution to the flicker problem.

Consider another example. A 13.2 kv. radial feeder, 10 miles long, has an arc furnace near its end. The furnace produces 1500 kva. swings causing 15 per cent voltage dips to customers near the furnace and a minimum of 2 per cent dips for customers adjacent to the substation. The fact that the lighting load on this feeder is distributed complicates the problem. The series capacitor must be so located and have such an ohmic value that, (1) as many customers as possible must be relieved of flicker trouble, (2) the customers near the end of the line receiving the 15 per cent dips must receive the maximum possible reduction in voltage dip, (3) the sudden voltage rise accompanying load swings to customers adjacent to the capacitor should be no greater than the maximum dip and in no case should it exceed 4 to 5 per cent above normal. Thus, a

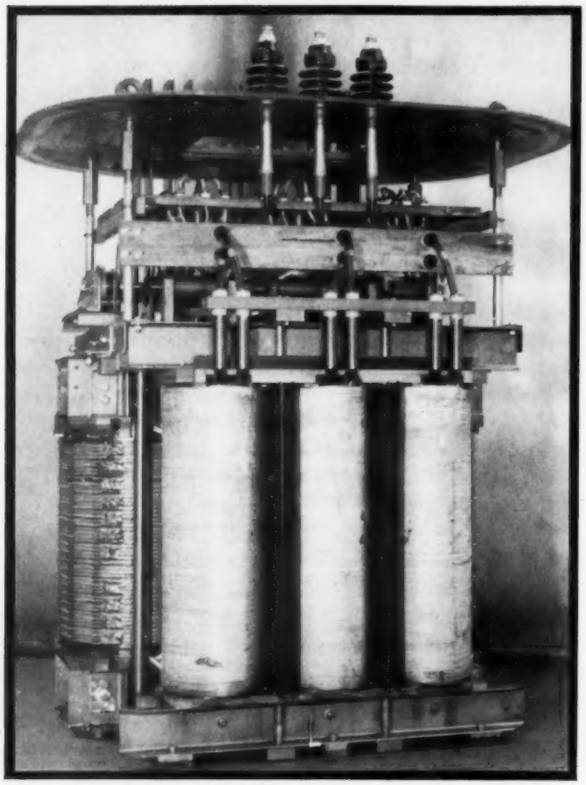


Figure 21—Interior view showing the high voltage side of 3750 kva., three-phase furnace transformer.

series capacitor to meet these requirements must necessarily be a compromise.

For this case, the best compromise is a series capacitor which will give a 10 per cent rise with load swing, located at a point on the feeder where the voltage dip due to the same load swing is 5 per cent or 3¾ miles from the substation. With this arrangement, as shown in Figure 17, the maximum voltage change to any customer, plus or minus is limited to 5 per cent. Since this is not within what are usually considered allowable limits for good regulation, the series capacitor here must be considered as only a partial solution.

In an application of this type, if the line impedance had been functioning as part of the furnace stabilizing impedance, additional impedance would need to be added at the furnace if the series capacitor is applied to the line.

THE SYNCHRONOUS CONDENSER

The synchronous condenser has been used effectively to correct flicker troubles caused by arc furnaces, particularly large ones. To be effective the condenser must be close to the fluctuating load. Following a sudden change in terminal voltage, a condenser absorbs instantly both kilowatts and reactive kva., thereby diverting a part of the load fluctuation from the distribution system and minimizing voltage fluctuations appearing thereon. A condenser can absorb kilowatts only for a relatively short time following a load fluctuation, perhaps 15 cycles, and, of course, to absorb a sustained increase in reactive kva., it must be equipped with automatic field control.

The extent to which a condenser can correct for flicker is largely a function of the ratio of condenser transient reactance to system transient reactance back of the fluctuating load, the condenser being most effective when this ratio is a minimum. To obtain best results a condenser having lower than normal reactance —perhaps 30 to 50 per cent or less—would be applied. Even then the ratio of condenser to system reactance is likely to still be so high that a buffer reactor, see Figure 18, to increase the system reactance back of the furnace bus, is necessary before any substantial reduction in voltage flicker can be effected.

Some care must be used in applying a buffer reactor. The more the better so far as flicker reduction is concerned, but too much will interfere with proper and efficient furnace operation and may also considerably impair the stability of the condenser.

Experience seems to indicate that the application of the synchornous condenser is limited to large furnace applications, and also to cases where a reasonably small amount of flicker correction is needed; for example, reducing a 4 per cent dip to a 2 per cent dip as illustrated in Figure 19. Where the correction needed might be reducing a 10 per cent dip to a 2 per cent dip, the cost of the condenser and buffer reactor combination might be unreasonable.

Another factor of importance bearing on the economics of condenser applications is the need which there might be for normal reactive correction, as distinct from flicker correction, at the furnace location. Any additional value of synchronous equipment, of course, simply augments its attractiveness as a means of flicker correction.

INHERENT SYSTEM DESIGN

Loss of voltage in a power system is caused by current flowing through the various impedances of a system. Loss of voltage can be reduced by reducing the impedance and also by reducing the currents. The principal method of reducing currents is by power factor improvement. There are several means, however, of reducing impedances to give effective reduction in voltage drop, whether it be fluctuating or constant.

If a load has a high power factor, a large part of the voltage loss it produces is due to the resistance of the system. If it has a low power factor, most of the voltage drop is probably due to the reactance in the system.

Thus, we find that with loads on long rural lines of small conductor size, resistance drops predominate and the reduction of reactance gives only partial voltage reduction. Whereas, with loads on heavy copper urban feeders, reactance voltage drops predominate.

Usually, fluctuating loads have a large reactive component. With the arc furnace, however, although the reactive component is substantial, the kilowatts usually predominate, as evidenced in Figures 7, 8 and 9. Thus, even for such loads, the resistance as well as the react-

ance of a distribution system must be reduced to obtain the maximum reduction in voltage loss.

Not a great deal can be done in reducing the reactance of overhead lines. Conductor size does not affect it much, and conductor spacing cannot be reduced below certain allowable limits for other reasons. Substantial reduction in reactance can be obtained by going to insulated cables; however, at a great increase in cost. Resistances with either insulated cables or overhead lines, of course, vary directly with conductor size, or very nearly so.

Voltage drops may be greatly reduced by going to higher circuit voltages, the per cent varying inversely as the square of the circuit voltage. This entails more expensive lines, as well as terminal equipment, and the cost of such a solution must be carefully balanced against the value of the load for which the correction is made.

For controlling voltage with normal load changes, regulators and regulating equipment are widely used on distribution systems, rather than some of the expedients described above. For fluctuating loads such as arc furnaces, however, experience seems to indicate that the majority of voltage troubles are corrected by changes in the inherent system design.

A common solution is to place several arc furnaces and other loads of a similar nature, which are not sensitive to reasonable voltage dips, all on one feeder. If necessary, this feeder can be served from a separate bus and special transformer bank designed only for such loads. This has been found to be a simple and economic solution, especially in large cities where such loads are confined to industrial areas.

In other instances, a subtransmission circuit serving a distribution substation, but being necessary only to supply firm capacity under emergencies, is operated normally isolated from the substation bus and serving arc furnace and other non-voltage-sensitive loads. The circuit can, of course, be quickly switched to the substation bus under emergency conditions. Such an arrangement is illustrated in Figure 20.

Arc furnace load swings, while occurring frequently, are nevertheless erratic, and it is reasonable to assume that the percentage deviation in load would decrease with several units operating in parallel on the same bus or circuit. Jones and Stearns have reported the diversity effects obtained with two 10,000 kva. furnaces.* The maximum load swing was found to be only 20 per cent greater with two units than with one. This leads to the conclusion that a plausible method of minimizing flicker would be the use of several small furnaces rather than one large one.

THE MOTOR-GENERATOR SET

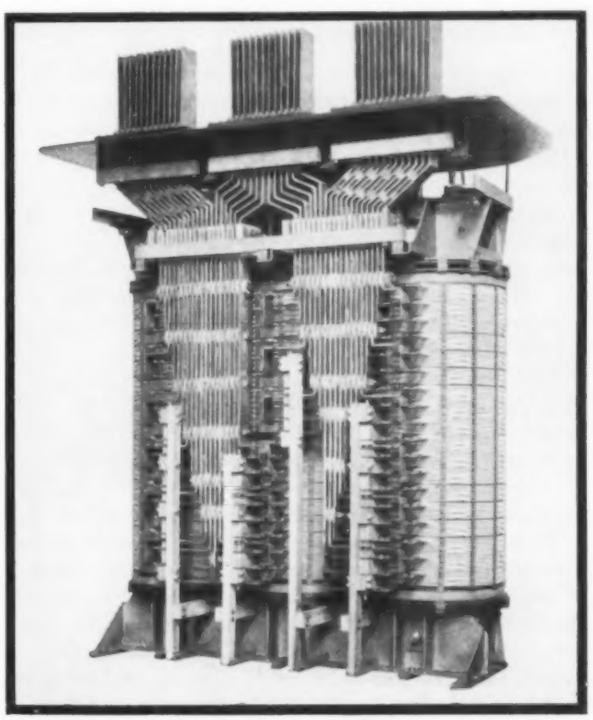
The motor-generator set has been used to a limited extent to serve arc-furnace loads. From one point of view, the motor-generator set offers an ideal solution to the ravages of a fluctuating load because it severs all electrical connection between the load and the distribution system. It is practically 100 per cent effective in absorbing rapid swings in reactive kva. This characteristic makes it well adapted (except possibly for its cost) to such loads as welding loads of low power factor and poor load factor.

The motor-generator set is also effective in reducing kw. swings because of the cushioning effect of the rotational energy of the two machines. Energy absorption can be augmented by the addition of a flywheel to the rotor.

In an arc furnace, the kw. swings may or may not exceed the reactive swings. This depends largely on the ratio of total resistance to total reactance in the circuit. With a furnace located at the end of a long line, the swings are likely to be kw. With a furnace on a heavy bus close to the source, the swings are more likely to be reactive.

Figure 7 shows typical load changes during the start of the melt on one phase of a small 3-phase arc furnace, the curves shown are envelopes of oscillograms of the quantities indicated. Note here that at one point, both kilowatts and reactive kva. about doubled in one second, but the kw. change was 190; whereas, the reactive change was 120. Probably kw. swings exceed in magnitude the reactive swings on most arc-furnaces. These swings may take place in a cycle and be sustained for as much as 15 to 20 seconds before changing. Also, considering its whole duty cycle, the arc furnace has a high load factor. These two characteristics of the arc furnace load are ones to which the motor-generator set,

Figure 22—Interior view showing the low voltage side of a 12,000 kva., three-phase furnace transformer.



*"Large Electric Arc Furnaces—Performance and Power Supply," by C. M. Stearns and B. M. Jones, A.I.E.E. Winter Convention, Philadelphia, 1941.

with or without a flywheel, would normally not be considered particularly adaptable. However, if the motor-generator set can be shown to be economically feasible, it can be relied upon to give substantial improvement in arc-furnace flicker.

It should be noted that if a motor-generator set is used, the induction-synchronous set is the preferable for smoothing load swings, but the synchronous-synchronous set has the advantage of being able to operate at high power factor or of operating to give reactive correction.

Still another solution to the problem of serving arc furnace loads is to so arrange the melting schedules such that the initial period of melting down comes at the time of day when sensitive loads, *i.e.*, lighting, etc., are not in service. Thus, starting the melt in the early morning hours would probably result in no flicker complaint.

Also, the melt might be started at times of light load and served individually from a feeder which is required for other purposes at times of peak load.

Solutions such as these naturally depend on system conditions and the adaptability of the furnace to special schedules.

CONCLUSIONS

The arc furnace falls in that class of loads which produce the most objectionable flicker. Load swings of from 200 to 300 per cent may occur in one cycle, last five or more cycles, and 5 or 6 such swings may occur in a second.

Because the arc-furnaces have a high load factor and are thereby profitable, as much as $10 per kw. of furnace capacity (and probably more) can be spent to correct flicker troubles.

The following are total or partial solutions to the flicker problem, most of which have been tried successfully.

1. Series capacitor.
2. Synchronous condensers.
3. Motor-generator sets.
4. Changes in inherent system design.
5. Diversity effects using small units.
6. Special time-operating schedules.

Special attention to the inherent system design appears to have been the most widely accepted method of correction.

However, the variables and influencing factors associated with the problem are so diverse that the solution cannot be generalized. Each application should be studied as a special and separate problem.

DISCUSSION

PRESENTED BY

H. P. ST. CLAIR, *System Planning Engineer,* American Gas and Electric Service Corporation, New York, New York

L. W. CLARK, Detroit Edison Company, Detroit, Michigan

C. B. MORIN, Ohio Power Company, Canton, Ohio

F. W. BROOKE, *Vice President,* Swindell-Dressler Corporation, Aspinwall, Pennsylvania

B. M. JONES, *Planning Engineer,* and C. M. STEARNS, *Sub-Section Engineer,* Duquesne Light Company, Pittsburgh, Pennsylvania

F. M. STARR, Distribution Systems Section, Central Station Engineering Department, General Electric Company, Schenectady, New York

H. P. ST. CLAIR: I should like to comment on only a few phases of this paper. In the first place, the authors did well to open the entire subject by their discussion of flicker, which, of course, is one of the problems that make electric furnaces sometimes difficult for utility companies to serve. We have had some experience and some grief in that respect but probably, on the whole, have been rather fortunate.

The authors have given a good discussion of this problem of flicker tolerances, basing their judgment largely on rules adopted by one large eastern utility and upon the results of extensive investigations made by the Utilities Coördinated Research, Inc. We have no exceptions to take on this discussion.

Both our reasoning and our experience, however, differ from that of the authors in respect to the nature of the power swings which, in turn, are the cause of the flicker problem. If it were true, as the authors have stated, that these power swings were predominantly kilowatts, it would not be such a difficult problem since, in the heavy circuits which we use, resistance is fairly small compared with the reactance. Therefore, if the power factor were high, the voltage drop produced by the swings would be comparatively small due principally to resistance drop.

However, it has been our experience and it seems to us that it is reasonable to expect that the power swings taken by electric furnaces are at fairly low power factors. This also seems to be the experience of others as indicated by papers referred to in the authors' bibliography.

In Figures 7 and 8 the authors have reproduced the envelopes of oscillographic records taken on a certain electric furnace, and apparently they found during the initial operation of the furnace that the kilowatts predominated over the reactive kva. This instance, if correctly reported, undoubtedly gives a basis for the authors' conclusions in this matter. On the other hand, judging by our experience and that by the authors mentioned above, this seems to be an isolated case. To substantiate our conclusion that reactive kva. generally predominates in the electric furnace swings rather than kilowatts, I should like to refer briefly to two of the papers mentioned in the authors' bibliography and to describe our own experience.

First, I should like to refer to the paper by Mr. L. W. Clark entitled "Power Company Service to Arc Furnaces." Mr. Clark states in this paper that the current swings to be expected during the first 15 or 20 minutes of the preheating period will be at a power factor on

the order of 50 per cent which means that the reactive component is nearly twice as great as the kilowatts.

Also in the paper by Messrs. B. M. Jones and C. M. Stearns entitled "Large Electric Arc Furnaces—Performance and Power Supply," the statement is made that furnace load swings are generally at a very poor power factor. In that paper, the authors have selected from some graphic records of furnace operation typical values showing the input to a 25-ton furnace. These values have been listed in Table I. In this table the swings are given in terms of the high and low point of the actual power swing, that is, in terms of the load at the beginning of the swing and the load at the highest point. In all of these cases it is noticeable that the power input at the low point of the swing is at a fairly high power factor, whereas the input at the top of the swing is at a very much lower power factor.

While it was not so expressed in the paper, I believe a simple and convincing way to analyze these swings is to consider that the actual swing is a power increment added to the low value. In other words, if you take the input at the top of the swing in terms of its kilowatt and reactive components and subtract from that the input at the beginning or bottom of the swing, you will have in effect the increment of load thrown on the power system by the furnace swing. You can then take this increment and apply it to the impedance of the power supply circuit and obtain the actual instantaneous voltage drop which that swing will produce.

Taking the five values in the Jones and Stearns paper and subtracting for each of these the low point of the swing from the high, I have obtained for each case the increment value which is actually somewhat higher in magnitude of total kva. than the figures given by the authors. Furthermore, the power factors of this increment are quite low, varying from 56 per cent maximum to a low of 10.4 per cent power factor. This means for these cases that the reactive component varied from one and a half times to nearly ten times the kilowatt component.

Coming to our own experience, I had occasion to watch the indicating ammeters and wattmeters on the circuits supplying a large electric furnace in Benton Harbor, Michigan. This furnace at the time was causing a serious voltage flicker problem. In watching these indicating instruments, I observed that, while the kilowatts seemed to remain relatively unchanged or, at least, with comparatively small swings, the ammeter was swing all the way across the scale. While I took no graphic records or oscillograms, I felt convinced, nevertheless, from these observations that the reactive kva. swing was by far the predominating component, probably at least three times the kilowatts.

In another case we have taken a number of graphic charts on the input to a large furnace, and there again these charts show that the current or kva. fluctuations are much higher than the kilowatts, indicating that the reactive component must be predominating.

All of this is quite pertinent to the problem of voltage fluctuations and indicates that it is, in fact, a little tougher than the authors have found from their results.

The authors have pointed out the limitation of synchronous condensers in controlling this voltage flicker situation. I might say that in the Benton Harbor case a 15,000 kva. synchronous condenser operating directly on the 27,000 volt bus from which the furnace feeders were supplied had very little effect and was nearly useless as far as fluctuations were concerned. In this situation the only solution which we could find, and as far as I know this still remains the only adequate solution for such a problem, was to do what the authors have suggested under the heading of "Inherent System Design" and illustrated in Figure 20, and that was to supply the furnace feeders through a separate transformer bank stepping down to an isolated bus. In this case it involves stepping down from 132,000 volts to a separate bus. The furnace was supplied over two isolated 27 kv. lines connected to this isolated source. In this way the fluctuations were in effect removed from the main 27 kv. bus supplying the rest of the system load at that point. Of course, the fluctuations still remained on the 27 kv. line supplying the furnace load but only the single customer was affected and was able to get along with these fluctuations.

I feel that the authors are quite right in stressing the importance of inherent system design in taking care of this problem. It is undoubtedly the most effective way to handle the situation. Unfortunately, however, the systems are generally in a rather advanced state of design already when the furnace loads are considered and have to be taken on, so that the inherent system design cannot easily be changed, at least without spending a considerable amount of money to do so. On our own system, except for the one instance described, we have been rather fortunate in that our large electric furnace loads have been located at points where we had heavy concentration of capacity, and the flicker problem has not so far become serious.

L. W. CLARK: This paper gives an excellent summary of the various considerations involved in providing service to arc furnace loads. The conclusions arrived at are sound, and I only wish to discuss certain parts of the paper about which there might be some chance of misinterpretation as well as some slight difference of opinion.

In discussing the addition of series reactance for stabilizing the arc, it is pointed out that, while this is advantageous from the standpoint of smoother operation, it decreases the average power factor and thus increases the average voltage regulation. While this statement is entirely true, we believe it is more important that the magnitude of fluctuations be reduced, even at the expense of lower average power factor, because unless the fluctuations can be controlled to a point where the furnace can actually be served on a given line or substation, it often means that complete new facilities must be provided for the furnace alone, which is almost certain to be far more expensive than the slight additional capacity which might be needed to take care of the increased average kva. due to the lower power factor.

The paper points out that the lowering of power factor is especially detrimental because in most cases the ratio of reactance to resistance in the impedance of the supply system is at least 2 to 1. The ratio is often greater than this and in some cases may even be as high as 5 to 1 where the impedance is composed principally of substation transformer capacity and a relatively short line. However, high ratios of reactance to

resistance are even more detrimental in the relation to flicker troubles than they are in relation to average load regulation because the large current fluctuations are at considerably lower power factor than the average load. Thus, much more is gained in flicker reduction per unit of reactance added to the furnace circuit than is lost in average regulation due to lowered average power factor.

Several curves are given to illustrate the operating characteristics of furnaces at different parts of the heat cycle, with kw., kva. and reactive kva. plotted against time in seconds. These curves are more indicative of average rather than instantaneous conditions, such as cause lamp flicker. While they show regular changes every 15 cycles or quarter-second, it should not be inferred that any such regularity of change actually occurs. Most oscillograms show that during the melt-down many fluctuations occur irregularly from every 2 or 3 cycles on up to more or less steady operation near the end of the refining period.

From the curves the conclusion is also drawn that the kilowatt fluctuations are of greater magnitude than the reactive kva. fluctuations. This may be true of some of the minor changes but the large fluctuations, which are, in effect, actual short circuits, are predominately reactive in nature and are usually at a power factor somewhere between 30 and 60 per cent. Again, the curves more nearly represent average rather than momentary conditions and, as all arc furnaces operate at considerably better than 70 per cent average power factor, the average kilowatts are always greater than the average reactive kva. However, the percentage instantaneous change in reactive kva. is in many cases greater than the percentage change in kilowatts and will practically always be more troublesome from a flicker standpoint than the same amount of kilowatt change due to the high ratio of reactance to resistance of the supply system as previously discussed.

Under the section on "Predetermination of Allowable Furnace Load," it stated that heretofore it has been considered necessary to collect a multiplicity of data and to perform laborious calculations in order to determine the effect of a particular furnace on the power supply system and suggested that much of this effort can now be eliminated by obtaining the reactance of the furnace installation directly from the furnace manufacturer. Practically all of the testing done in the past has been for the purpose of observing the maximum current fluctuations that may be expected from a given size furnace which, it is true, can be readily calculated if the reactance is known. However, it has always been difficult to obtain in advance from the manufacturer either the reactance of the furnace circuit or the maximum current fluctuations which might be expected, hence the necessary testing of similar existing installations. Once either of these values is known, the calculation of flicker magnitude is a simple matter, although it is still necessary to fall back on testing and observation in the determination of the frequency of occurrence of the different sized fluctuations.

It is insufficient when considering an actual installation to assume that the reactance will be approximately 50 per cent with a corresponding maximum current change of twice the furnace rating as suggested in the paper. Tests of different sizes of three-phase furnace installations indicate that the maximum three-phase swing is about twice the rating of the furnace transformer only for installations around 4000 to 5000 kva. in size. Furnaces that are 1500 kva. and under usually have maximum swings in the order of three times their rating, and on the opposite end of the scale (10,000 kva. and above) the swings are usually less than 1½ times their rating. While it is probably true that the swings of the smaller furnaces could be kept within twice the rating, actual operating experience shows that, for some reason or other, the higher swings are encountered. It may be due to the fact that in the attempt to push production, secondary voltages are raised and reactance cut out of the circuit to a point where increased fluctuations result and, in many cases, production actually suffers rather than improves. On the other hand, with the large furnace installations (8000 kva. and above) every attempt is made to cut out unnecessary reactance in the circuit and, even with short, interlaced busses, there is still sufficient stabilizing impedance to insure relatively smooth performance.

C. B. MORIN:—I agree heartily with the conclusion arrived at in this paper as to the importance of analyzing the method of serving arc furnace loads.

I wish, however, to emphasize the importance of regulation, especially from the flicker standpoint. The authors have handled this matter admirably but I wonder if those in attendance realize the problem which is confronting the utilities today. Standards of regulation are like all standards, they change from day to day and year to year, and the standards of regulation that were in effect many years ago could not possibly be accepted for satisfactory operation of current consuming devices on utility lines today. This is brought about due to two reasons.

One is that the development of new devices, utilizing electricity, now demand very close tolerances of regulation in order to give satisfactory service.

The second is the attitude of the public at large has changed with the passing of years and they are demanding from us closer regulation.

There is nothing more detrimental to close regulation, and I am including flicker regulation in this, than the operation of electric arc furnaces for melting steel.

These standards, imposed upon us by the reasons I have just enumerated, compel utility companies to be ever watchful in adding to their system individual loads that would seriously affect their service to other customers. This watchfulness naturally transfers itself into investments in facilities to protect our general service. This means that sufficient guarantees will have to be made by operators of electric furnace equipment in order to justify the investment on the part of the utilities in such protection to their general service.

The authors have pointed out the matter of location of electric furnaces with respect to utility system design. I just wish to emphasize this very important point. For example it is utterly out of the question to even consider transferring all or any portion of the heavy melting electric units that we are now serving in the Canton area to receiving service from any stub end transmission lines and hope to give service to our other customers in that area in accordance with the generally accepted standards.

The successful operation of these heavy melting units in Canton is due to the exceptionally heavy reservoir of capacity available at this point.

F. W. BROOKE:—The comments I would like to make are on the points brought up by Mr. Clark, rather than on the paper itself, which was excellent.

In regard to Mr. Clark's discussion, he stated that it was rather difficult to get reactance information on a furnace installation. That is partly true, and it is true because you must divide a furnace installation from a reactance point of view into two parts: that is to say, the transformer itself, and the furnace.

In the case of a transformer, a furnace builder can definitely specify reactance. If it is a large furnace with 10,000 kva. or larger capacity the furnace manufacturer's problem is to keep the total impedance of the transformer down to a minimum, and they usually go down to the order of four per cent, with no external reactance, unless something in the line justifies external reactance.

In the case of a smaller furnace requiring, let us say, a 3000 kva. transformer the furnace manufacturer gives the customer a very flexible range of external reactance values in the transformer. A furnace of this kind might require a total reactance in the transformer of 35 per cent. The external reactance portion of this is equipped with taps ranging in number from 2 up to as high as, in one particular case, 14 taps.

When a furnace of this kind goes into service, more particularly in the foundry industry, it is very rarely that the customer makes use of this flexibility of reactance and I think that the power companies together with the furnace builders could do a lot of service to the industry as a whole by going to these customers and pointing out what a valuable tool a transformer of this kind is, both from the power company's point of view and the furnace operation point of view.

I could point out case after case where there have been as high as 10 to 12 taps in the reactance and where no change has ever been made after the furnace is started into production. Operating conditions often change and trouble may be developed on the power system which would affect the best operating conditions, but nothing has been done to find the optimum amount of reactance required to give the most efficient overall operation.

In the case of the furnace itself, the furnace builder is not quite so fortunate. He can build his furnace to give a particular reactance or impedance under the conditions set forth at the time the furnace is sold as a unit. When he begins to install the furnace or make a shop layout he often finds many local environments on the secondary side of the furnace which changes the total impedance of the installation as a whole. There may be a large steel column that he has to dodge. There may be a heavy steel crane girder in the way. These all have induction values and affect the total impedance of the system, which only become known after the furnace has been sold and the power company has arrived at the method of supplying this particular unit with power.

One big factor in the furnace system is the flexible leads. Flexible leads usually form the item of greatest variation and are one of the big troubles the furnace builder has to contend with.

I would like to make the plea to the power companies, furnace builders and the customers to investigate their operating conditions and see whether or not they have taken advantage of the range of reactance in their transformer so that the best efficiency is being obtained.

B. M. JONES AND C. M. STEARNS: Our experience has been similar to that of Messrs. St. Clair and Clark, in that furnace swings were larger by far in reactive kva. than in kilowatts for a 10,000 kva. installation we tested recently. The authors' data, we believe, were on small furnaces, while our data are on large furnaces, and we feel that this might explain the difference.

With respect to Mr. St. Clair's reference to the power factor of the increment swings in the paper presented by Mr. Stearns and myself at the January, 1941, A.I.E.E. meeting, I would like to say that elsewhere in that paper, but not in the table, there is reference to increment change in load at 54.5 per cent power factor for one furnace for a swing of 8600 kva. Where there were two furnaces in operation, the increment power factor change was 52 per cent, with a kva. swing of 10,580. We just tabulated the power factor at the beginning of the swing and at the end, and then made reference to it twice in the paper. Table II of this discussion contains these data.

We have had a 10,000 kva. furnace in service since March, 1940, on a 66 kv. 4/0 equivalent line nine miles long. Another 10,000 kva. furnace went in service in August last year, one more 10,000 kva. furnace went in last week, and one more goes in next week . . . all in the same plant. We have complete test records of the first two, including many feet of oscillographic records and meter charts, but we do not have anything on the others yet. Tests on the four furnaces are scheduled for this summer.

We tested two furnaces together, and believe there will not be a great increase in the swing of the four furnaces over the two operating together. Two furnaces give a 20 per cent increase in the magnitude of the swings over one furnace.

On the first two 10,000 kva. furnaces, the furnace people of their own will and accord, with us as cheer leaders, actually used a lower voltage tap when starting the meltdown. The customer determined the most economical maximum voltage for optimum furnace operation, and set the transformer taps accordingly. Thus, the most suitable voltage taps are brought out to the wheel, and no others are available to the furnace operators. This bears out Mr. Brooke's reference to the voltage taps as being a very useful tool.

In another case, on a 5000 kva. furnace we found that the arc was quite unstable, and tried to get the furnace operators to use lower voltage taps when starting. But they just cranked it up to the maximum and banged away. We actually put kilowatt hour meters on this installation and measured the electric energy consumed by the furnace, and found that there really was more energy put into the furnace with a somewhat lower voltage tap during starting, due to the arc being stable, than with the higher voltage tap and the intermittent arc. But we just could not convince the furnace people of this, so they are banging away on the high voltage taps.

In the authors' paper, under the subject of predeter-

mination, they indicate that it is necessary in some cases to determine what the effect of the furnace will be prior to installation. We believe that it is necessary in all cases, unless you have one like it in the same plant, or at a spot on your system, of similar stiffness. I would strongly advise trying to find out what the effect will be before you put it on.

Still another point under predetermination, wherein the authors refer to system short circuit data. It is usual practice for power companies to make short circuit studies on the three phase symmetrical current basis. The single phase values are then determined as they are twice the three phase values.

The authors made a very good point in referring to the effect of single phase swings because the lighting comes on single phase. This is much more serious than three phase swings. I think Mr. Clark and the Detroit Edison Company are very fortunate in having what they call a "flicker bus," and their large fluctuating loads more or less collected in one territory, and that they can build a substation for such loads and the flicker does not bother the residential customers. We are not so fortunate.

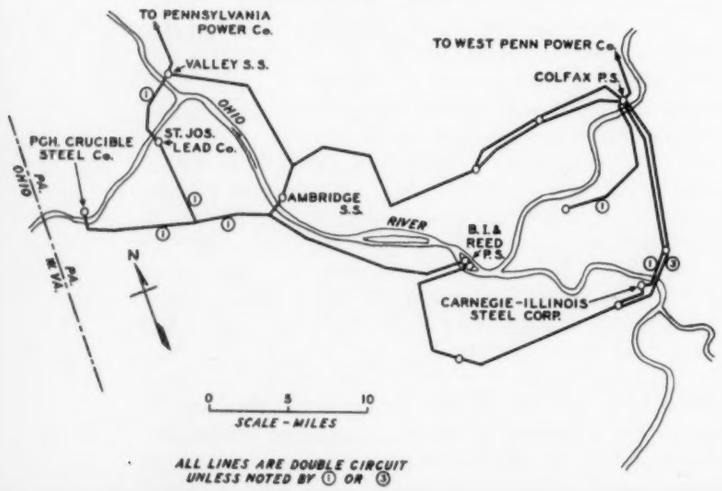
We have used series capacitors for correcting voltage flicker (not on arc furnaces), and have been quite successful with them. But they have to be "custom-built" for the job, and they cannot just be taken down and hauled away and used somewhere else. They will not necessarily fit; in fact, they very likely will not.

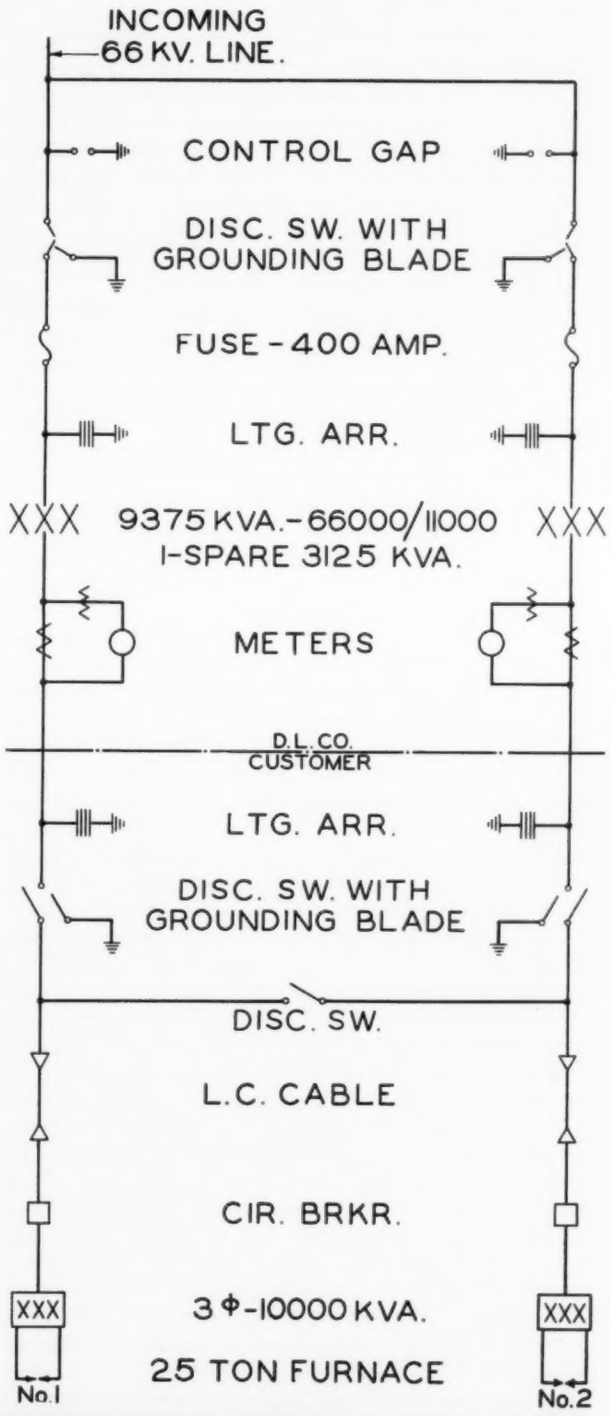
We believe one of the most helpful things in the authors' paper was the short-cut method suggested of determining in a preliminary way whether a furnace was going to be too big or not. If your preliminary studies indicate that it will be satisfactory, it might be safe to put it on. However, if your preliminary studies indicate that it is not satisfactory, caution is the word, and more investigation may be necessary . . . or you might find yourself spending a lot of money to fix it up afterwards.

I believe the flicker problem is the most important. Power companies today do not worry about the size of the load, or where it is, so long as it does not flicker. If it is a steady load, you can easily build one line or two lines or even three lines, and it is just a question of making a little profit on it. But if it flickers, it is a serious matter.

Figure 1 (below)—Diagram of Duquesne Light Company 66 kv. power lines.

Figure 2 (right)—Diagram of power supply and furnace substations for arc furnace installation.





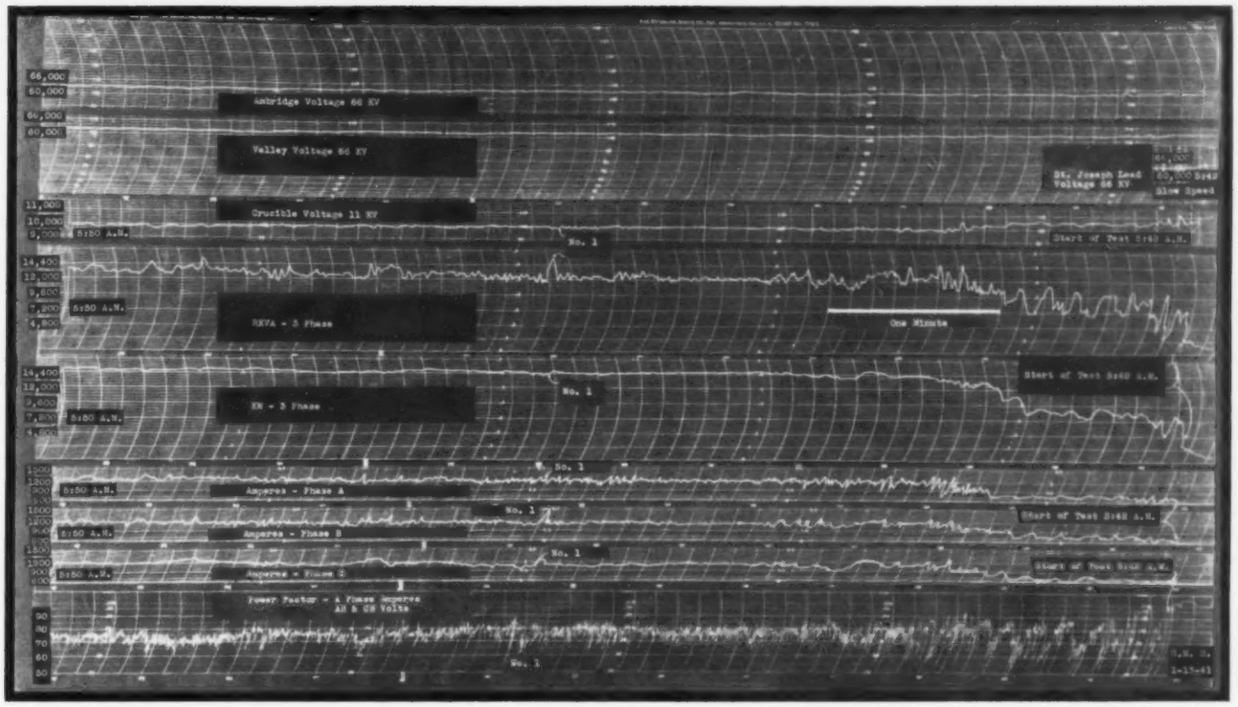
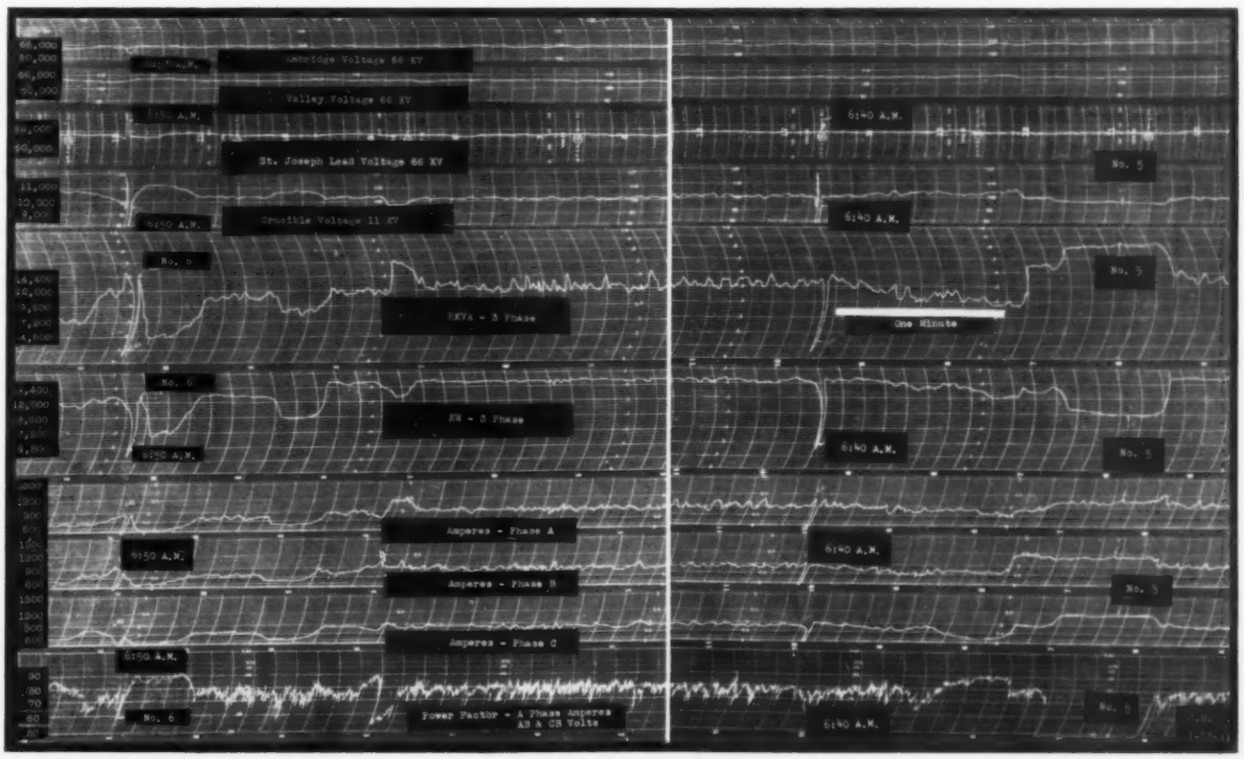


Figure 3—Test data from two arc furnaces melting down simultaneously (start of melt).

TEST DATA

We have made very complete tests of the first two 10,000 kva. furnaces at the Midland plant of the Crucible Steel Company of America, and some of these data are included in Figures 1 to 6, and Tables I and II. These data apply to two furnaces operating simultaneously. The tests on one furnace and on two furnaces covered a period of approximately 6 hours; and during

Figure 4—Data from two furnaces of Figure 3, about an hour after start of meltdown.



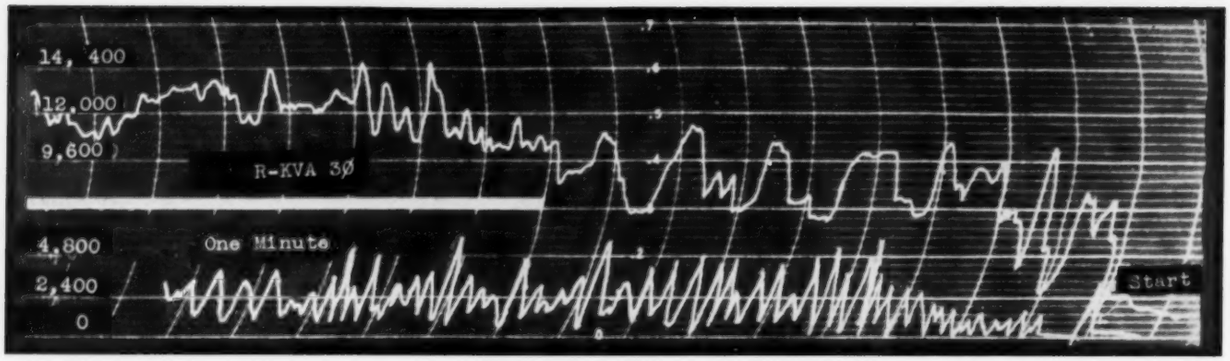


Figure 5—Chart showing comparison of reactive kva. swings with one and two furnaces operating.

the tests on the two furnaces, the simultaneous meltdown covered approximately 1¾ hours.

Complete data on the tests on the first furnace alone, and a little data on two furnaces, are contained in an article entitled "Large Electric Arc Furnaces—Performance and Power Supply," published in *Electrical Engineering*, July, 1941.

Figure 1 shows the Duquesne Light Company 66 kv. lines and power stations. The extension to reach Crucible Steel is 9 miles and it was tapped on an existing line between St. Joseph lead and Ambridge substation. This line is a 4/0 equivalent 66 kv. line, and has the very latest facilities in lightning protection. Incidentally, this line was built in the dead of winter, in a very deep snow; in fact, the snow was so deep that at times the crews could not find the markers for the pole sites.

Figure 2 shows a diagram of the power supply substation and furnace substation. The 11 kv. bus tie

TABLE I

CRUCIBLE STEEL

Test Data of Two Furnaces Melting Simultaneously

Test 5:30 A.M. to 7:00 A.M. on September 18, 1940

Point number on meter charts	Kw.	R-kva.	Calculated kva.*	Calculated three phase power factor	Charts single phase power factor	Amperes at 11 kv.			Voltages			
						A	B	C	Crucible	Ambridge	St. Joseph	Valley
1	14,160	15,360	20,900	67.7	55	1260	1500	1290	98.5	104.5	.....	102.5
2	12,960	18,800	22,850	56.7	50	1500	1440	1590	95.0	105	104	102.5
3	14,300	17,300	22,500	63.5	54	1415	1380	1380	97.0	106	105	103.5
4	13,700	17,900	22,550	60.8	50	1500	1410	1340	95	106.5	104.5	104
5 High	9,600	20,150	22,350	43.0	50	1440	1100	1470	96	106.5	105	104
Low	15,360	13,920	20,800	73.8	..	....	....	....	.....	.....	.....	.....
Inst. change			1,550									
6 High	12,300	13,920	18,600	66.1	66	1160	1440	810	101	108.5	108.5	106.5
Low	6,600	4,560	8,020	82.3	82.5	....	....	....	112.5	.....	.....	.....
Inst. change			10,580									
7 High	11,900	11,600	16,400	72.6	75	1050	1110	750	102	107.5	106	105
Low	7,600	4,560	8,870	86.7	..	....	....	....	.....	.....	.....	.....
Inst. change			7,530									
Maximum non-simultaneous	15,700	20,150	.....	....	..	1550	1500	1590	114	109	110	108.5
Minimum	.....	.....	.....	....	..	....	....	....	94.5	104	103	102

Both furnaces on No. 4 furnace transformer tap (240 volts open-circuit).
All measurements are input to furnace transformers and adjacent to supply substation.
*Calculated on basis of three phase kw. and R-kva. input.

TABLE II

Load Swings and Demands of One and Two 10,000 Kva. Furnaces

	One 10,000 kva. furnace alone	Two 10,000 kva. furnaces melting down simultaneously
Maximum instantaneous load swing, lasting less than one second, three phase kva.....	8,600 kva. at 54.5 per cent power fector	10,850 kva. at 52 per cent power factor
Next largest instantaneous load swing, lasting one second or less, three phase kva.....	8,000 kva.	7,500 kva.
Maximum instantaneous load swing, lasting more than one second, three phase kva.....	14,400 kva.	22,850 kva.
Maximum 15 minute demand..	8,400 kw. or 9,900 kva. at 85 per cent power factor	15,600 kw. or 20,800 kva. at 75 per cent power factor

These data cover a period of one full heat approximately.

disconnect switches are normally open, but can be closed if necessary, thus carrying both furnaces at somewhat reduced operation on one transformer bank. The two additional furnaces will be installed with similar equipment. Thus, there will be four transformer banks, four furnaces, and three 11 kv. bus tie switches.

Figure 3 shows some test data on this installation with two furnaces melting down simultaneously. It is interesting to note that shortly after the start of the tests at 5:42 A.M., the kw. load builds up to approximately 14,000 kw., and that the violent fluctuations present at the beginning smooth out to a considerable extent within the first few minutes.

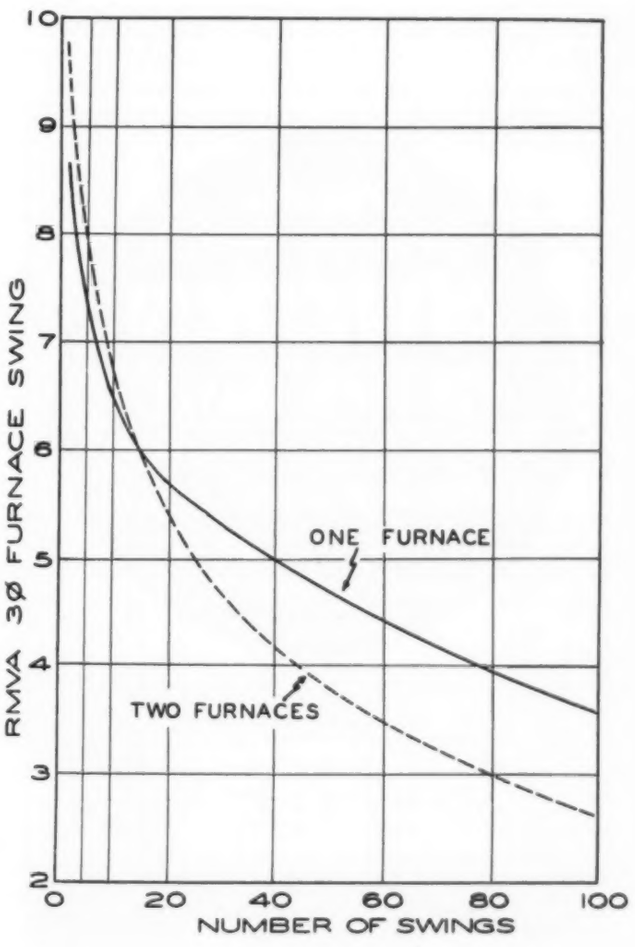
Figure 4 shows tests on two furnaces melting down simultaneously about an hour after the start of the meltdown. It is interesting to note here that at point 5, the kilowatts go down, reactive kva. goes up, the amperes on all three phases go up, the voltage drops, and the power factor also drops very materially. This phenomenon occurs rather infrequently, and we believe that it is caused by scrap falling into the molten metal and raising the molten level to a point where the electrodes are actually shorted in the liquid. Further explanation is, that the arc resistance having been materially reduced by the electrodes being shorted in the liquid, the current does increase but at a lower power factor than prior to the change. The increased current at a lower power factor causes a greater voltage drop, and actually a lower kw. furnace input but a greater reactive kva. This condition lasts for a relatively short period of time until the automatic control can back the electrodes out. On some of the modern furnaces, there is a 3/1 ratio in electrode movement, so that they are backed out three times as fast as they are lowered.

Figure 5 shows the comparison of the reactive kva. swings at the start of the test on one furnace alone, and corresponding data for two furnaces in operation. It is very interesting to note that the swings are much less frequent with the two furnaces than with one. Also, the magnitude of the maximum swings for the two furnaces is only 20 per cent higher than for one. (See point No. 6, Figure 4.)

Figure 6 shows the frequency of three phase swings for one furnace operating alone, and for two furnaces operating partially staggered and partially simultaneously. A special attempt was made to melt down simultaneously to get these swings, and the simultaneous operation during the heavy meltdown period last for about 1¾ hours of a total test time of 6 hours.

Table I shows comparative instantaneous figures as obtained from graphic charts, of kilowatts, reactive kva., calculated kva., calculated power factor, amperes in each phase, voltage supply to the customer's furnace transformers, etc. These values were taken during high instantaneous loads, and show the maximum instantaneous values obtained during the test; they also show the maximum instantaneous change in load or, in other

Figure 6—Curves giving comparison of frequency of three-phase swings with one and two furnaces operating.



words, furnace load swings. The points in this table refer to points on the meter charts, and some of these are shown on Figures 3 and 4.

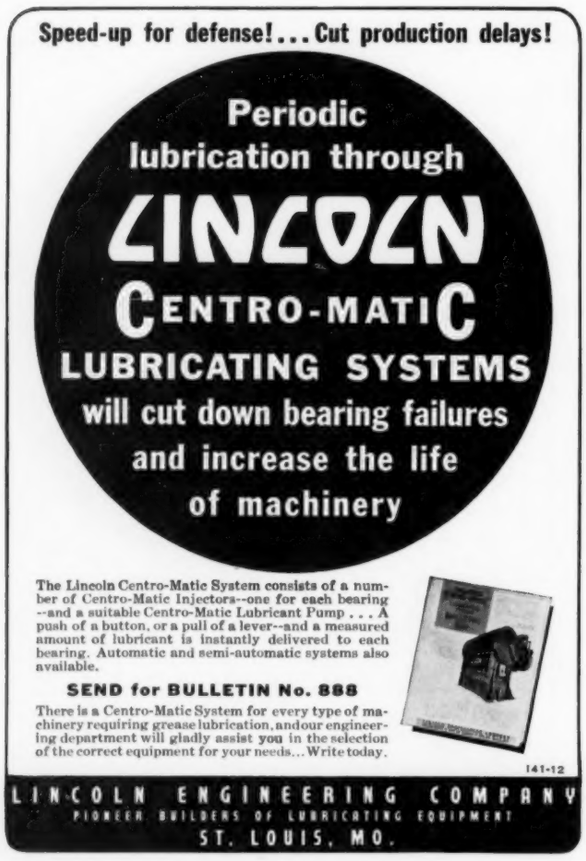
Table II shows a comparison of load swings of one furnace and two furnaces, including kw., kva., and power factor, for one 10,000 kva. furnace operating alone and for two 10,000 kva. furnaces operating simultaneously. For one furnace, the maximum swing of 8600 kva., three phase, occurred only once, the next highest was 8000 kva., three phase, occurring twice, and the next seven were between 7000 kva. and 8000 kva., three phase. For two furnaces, the maximum swing of 10,580 kva., three phase, occurred once, the next highest was 7500 kva., three phase, occurring once, and all other swings were materially less than 7500 kva., three phase. It is interesting to note that the instantaneous kva. load swings did not appreciably exceed the 15 minute demand.

For four 10,000 kva. furnaces in regular operation, the maximum 15 minute billing demand to date has been 21,792 kw., or 27,676 kva. at 79 per cent power factor. For the special tests on four 10,000 kva. furnaces in July 1941, with three melting down simultaneously and one refining, the maximum 15 minute demand was 23,100 kw.

F. M. STARR:—It is very gratifying to the authors that a very substantial amount of constructive and informative discussion has accompanied this paper. These collective comments by those engineers who have had wide experience in serving arc-furnace loads are highly essential to make a discussion on the subject complete.

In reviewing these comments, there appears to be only one point in question which needs further clarification before closing the discussion. Messrs. St. Clair, Clark, Jones and Stearns have all stated that their experiences indicate that reactive load swings exceed the kilowatt load swings. It was stated in the paper that probably in most cases the kw. swings predominated. This statement was based upon the fact that the majority of installations are relatively small, and that such test data as is available on this class of furnaces indicate that the kw. swings predominate. This was true of the test data published in the paper. However, it is undoubtedly true that reactive swings predominate in many cases, particularly with the larger furnaces.

As Mr. St. Clair has pointed out, when reactive swings do predominate, the flicker problem is even more serious.


Speed-up for defense!... Cut production delays!
Periodic
lubrication through
LINCOLN
CENTRO-MATIC
LUBRICATING SYSTEMS
will cut down bearing failures
and increase the life
of machinery
The Lincoln Centro-Matic System consists of a number of Centro-Matic Injectors--one for each bearing --and a suitable Centro-Matic Lubricant Pump . . . A push of a button, or a pull of a lever--and a measured amount of lubricant is instantly delivered to each bearing. Automatic and semi-automatic systems also available.
SEND for BULLETIN No. 888
There is a Centro-Matic System for every type of machinery requiring grease lubrication, and our engineering department will gladly assist you in the selection of the correct equipment for your needs... Write today.
141-12
LINCOLN ENGINEERING COMPANY
PIONEER BUILDERS OF LUBRICATING EQUIPMENT
ST. LOUIS, MO.

STATEMENT OF OWNERSHIP, MANAGEMENT, ETC., OF

IRON AND STEEL ENGINEER

(Required by Act of Congress of August 24, 1912)

Name of Publication: *Iron and Steel Engineer*, published monthly at Pittsburgh, Pa. (Report of October 1, 1941.)

Editor: Brent Wiley, Empire Building, Pittsburgh, Pa.

Business Manager: James D. Kelly, Empire Building, Pittsburgh, Pa.

Names and addresses of stockholders holding 1 per cent or more of total amount of stock: None.

BOARD OF DIRECTORS

1941

President, WILLIAM A. PERRY, *Superintendent Electrical and Power Departments*, Inland Steel Company, Indiana Harbor, Indiana.

First Vice-President, THOMAS E. HUGHES, *Superintendent of Maintenance*, Carnegie-Illinois Steel Corporation, Duquesne, Pennsylvania.

Second Vice-President, FRANK E. FLYNN, *District Manager*, Republic Steel Corporation, Warren, Ohio.

Treasurer, C. L. MCGRANAHAN, *Assistant General Superintendent*, Jones and Laughlin Steel Corporation, Pittsburgh, Pennsylvania.

Secretary, J. L. MILLER, *Assistant Chief Combustion Engineer*, Republic Steel Corporation, Cleveland, Ohio.

Past Presidents: JULIUS A. CLAUSS, *Chief Engineer*, Great Lakes Steel Corporation, Ecorse, Michigan.

C. CLARKE WALES, *Vice-President*, Hamilton Bridge Company, Ltd., Hamilton, Ontario, Canada.

Honorary Directors: JAMES FARRINGTON, *Electrical Superintendent*, Wheeling Steel Corporation, Steubenville, Ohio.

A. C. CUMMINS, *General Superintendent*, Youngstown District, Carnegie-Illinois Steel Corporation, Youngstown, Ohio.

WALTER H. BURR, *Electrical Superintendent*, Lukens Steel Company, Coatesville, Pennsylvania.

Director-at-Large, P. F. KINYOUN, *Combustion Engineer*, Bethlehem Steel Company, Lackawanna, New York.

Directors: FREEMAN H. DYKE, *Superintendent Blooming, Bar, and Hot Strip Mills*, Wheeling Steel Corporation, Steubenville, Ohio.

A. R. DIBBEN, *Assistant Electrical Superintendent*, Youngstown Sheet and Tube Company, East Chicago, Indiana.

GEORGE C. PFEFFER, *Superintendent of Power*, Florence Pipe Foundry and Machine Company, Florence, New Jersey.

W. J. WILSON, *Chief Electrician*, American Cast Iron Pipe Company, Birmingham, Alabama.

I. N. TULL, *Electrical Superintendent*, Republic Steel Corporation, Cleveland, Ohio.

STEPHEN M. JENKS, *General Superintendent*, Gary Works, Carnegie-Illinois Steel Corporation, Gary, Indiana.

L. J. GOULD, *Assistant Chief Engineer of Construction*, Bethlehem Steel Company, Bethlehem, Pennsylvania.

R. S. SHOEMAKER, *Lubrication Engineer*, American Rolling Mill Company, Middletown, Ohio.

C. H. WILLIAMS, *Assistant Chief Engineer*, Carnegie-Illinois Steel Corporation, Pittsburgh, Pennsylvania.

Managing Director, BRENT WILEY, Empire Building, Pittsburgh, Pennsylvania.

Known bondholders, mortgages and other security holders owning or holding 1 per cent or more of total amount of bonds, mortgages or other securities: None.

BRENT WILEY, Editor.

Sworn to and subscribed before me this sixth day of October, 1941.

NELLE J. BRENNAN, Notary Public

(My commission expires August 2, 1942.)

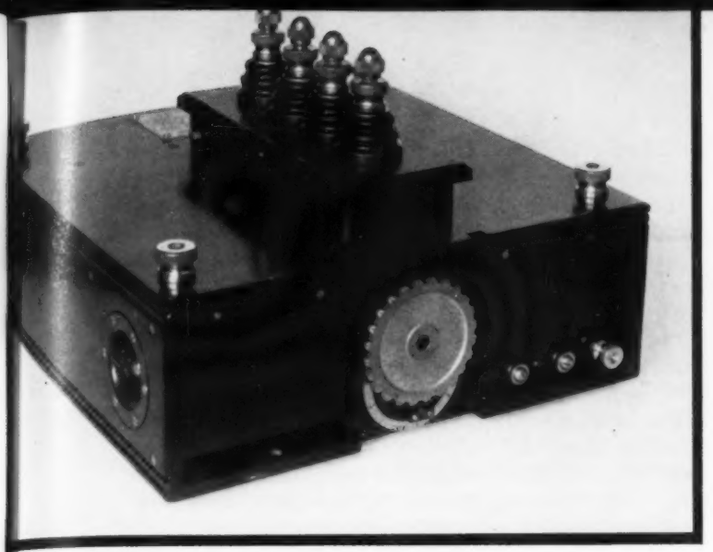


Figure 1

By Z. R. Whitehouse and
C. C. Levy*

Presented before Joint Meeting of A. I. S. E. and A. I. E. E. at Canton, Ohio, May 27, 1941

Surge Voltage Tests on ELECTRIC ARC FURNACES

▲ TESTS will show that many voltage surges occur during the operation of every electric steel arc furnace. Such surges are unusual in other industrial load circuits. It is, therefore, logical to look for the cause in the following conditions, which differentiate the furnace load from other industrial loads.

1. The furnace represents a relatively large concentration of power in a single piece of equipment.

For example, several furnaces recently installed have required 10,000, 12,000 and even 15,000 kva. transformers.

2. The furnace consumes energy through the medium of the electric arc.

The electric arc is inherently unstable, acting like a negative resistance. It is this characteristic that causes the tendency for the arc to go out as the current decreases. For the same reason, increasing current results in reduction of the voltage drop across the arc, tending to cause still higher currents to flow. In addition, the conducting path of ionized air and metallic vapors is subject to momentary irregularities, which may give rise to harmonics in the voltage wave.

3. Violent fluctuations of load, and frequent short circuits occur in the melt down period.

These are due to the frequent contacts between the electrodes and the charge until the pool of molten metal is fully established.

4. The operating procedure which makes it necessary to open the high tension circuit breaker from 30 to 100 times per day.

*Mr. Levy is in the Industrial Engineering Department of the Metal Working section, Westinghouse Electric & Manufacturing Co., and Mr. Whitehouse is electrical superintendent, Republic Steel Corp., Canton, Ohio.

It is necessary to open the circuit breaker because large changes in power input require that the secondary voltage be varied by the operation of the tap changer. In addition there are interruptions for slagging, deslagging, changing electrodes, charging, tapping, etc. The usual practice is to open the circuit after the electrodes have been raised, so that the breaker interrupts magnetizing current only.

Reviewing these four characteristics, we find that the furnace is not the only large industrial load in a single unit; steel mill motors of 8000 and 9000 hp. are used.

To overcome the inherent instability of the arc, sufficient reactance must be incorporated in the circuit. The reactive drop of secondary leads is high for large furnaces on account of the heavy secondary currents. The transformer has a fair amount of reactance and when necessary, additional reactance is used.

The fluctuations of furnace load and reactive kva. are troublesome when good regulation is desired by the public utility on the feeder supplying the furnace, but they are not the cause of voltage surges. This has been established by many tests.

It is in the last of the four special characteristics of the furnace load, namely the frequent switching of the circuit, that we will find the real cause of practically all the voltage surges in the operation of this type of arc furnace.

The existence of surges in the operation of arc furnaces has long been recognized, but because they resulted in so little trouble, no measurements were made until recently.

It is natural to ask why we are now concerned about these conditions. The fact that there have been relatively few cases of trouble has been used as a convincing argument to side step the problem entirely. However,

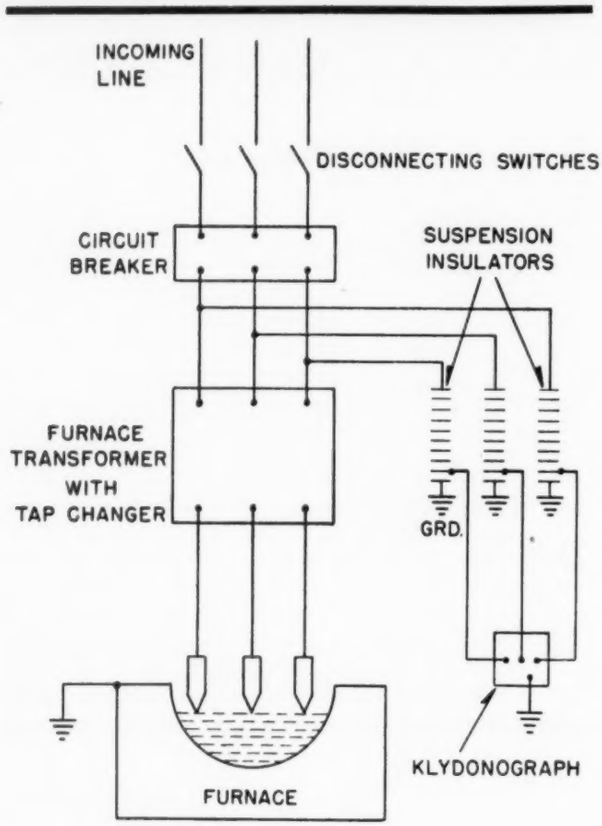
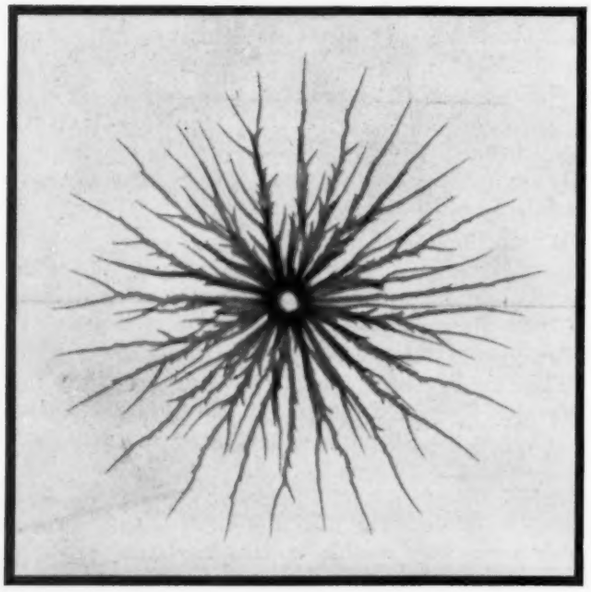


Figure 2—Diagram showing method of connecting klydonograph in arc furnace circuit.

Figure 3—Enlarged view of typical positive surge Lichtenberg figure obtained from klydonograph.



considering the recent increasing demand for electric furnace steel, it seems logical to investigate this phase of furnace operation before possible difficulties do arise. In addition, many operating engineers who now have electric furnaces added to their responsibilities would like to know how they can be made practically trouble-free.

The purpose of this paper then is to record for the benefit of the users of arc furnaces some actual test data, indicating magnitude of the voltage surges, as well as how often they occur. Some attempt is made to correlate them with switching and furnace operations. From this data and comparative tests made with certain surge protective equipment, we expect to show what steps can be taken to minimize the surges.

SURGE TESTS

The klydonograph shown in Figure 1 is the instrument used in making these tests. This device consists of a main drum which drives the film by friction, and two smaller drums which help to supply the friction. The main drum is a grounded metal cylinder covered by a thin micarta shell. The film is drawn over the surface of the drum at a speed of about ½ in. an hour by clockwork mechanism which drives the drums. The "feed" and "wind-up" film spools are held tightly against the main drum by means of the two smaller drums. Three insulated metal electrodes bear on the surface of the film, and are connected to points on a voltage divider, consisting of several suspension insulators connected between each line and ground as shown in Figure 2. The potential impressed on the electrode is recorded on the film as a trace or line. At least 2000 to 3000 volts crest is required to produce a continuous trace on the film representing normal potential. When normal voltage to ground exceeds 3000, the trace becomes quite heavy.

Surge voltages appear as the familiar Lichtenberg figures, the diameter of which is a measure of the crest voltage. Figure 3 is an enlarged view of a typical positive surge figure. The negative surge figures for a given crest voltage are smaller and quite different in appearance. For some reason the surge tests show that the great majority of the surges are of the positive type such as shown in Figure 3.

BASIS OF EVALUATION FOR SURGE VOLTAGES

Before a useful comparison of surge tests can be made we must consider the following:

1. Tests are important only when they have been continued for a sufficient length of time. This is due to the probability factor in the occurrence of surges.
2. Some arbitrary standard of what will be called a surge should be set up.
3. The average of a number of surges is more important than the maximum surge.

In these tests a surge has been defined as the normal line to neutral crest voltage multiplied by the factor

1.75. For example, on 23,000 volt, the line to neutral crest voltage is 18,800 and a surge will be 33 kv. or more to ground.

Test A—Location: Burlington Steel Company, Ontario, Canada.

Equipment: One 7500 kva., 13,800 volt, 25 cycle transformer.

These were the first klydonograph tests made. Previous to tests presence of surges were shown by flashover on secondary buses. A klydonograph was installed and three 10 kva. low voltage capacitors were connected on the low tension side to reduce the surges.

Klydonograph records were made on the low tension side using transformers to step up the voltage to a value which would give a reading on the instrument. However, due to the characteristics of the potential transformer the low tension surge records were not reliable.

Other records taken on the high tension side between the circuit breaker and the transformer, indicated surge of lower value than when the instrument was connected between the reactor and the transformer. The low voltage capacitors also appeared to be effective in reducing the surges.

Test B—Location: Northwestern Steel and Wire Company, Sterling, Illinois.

Equipment: Two 7500 kva., 13,800 volt, 60 cycle transformers supplying two furnaces.

Very complete tests over a long period of time were made at this plant and have been recorded in detail in a recent article.* Several different surge protective devices were tried out and the results obtained have been recorded. Figure 4 shows a typical record without surge reducing equipment. Figure 5 shows the effect of adding surge reducing capacitors to the circuit.

Equipment used:

High voltage capacitor: Three single phase, 13.8 kv., 0.25 microfarad.

Low voltage capacitor: Three 15 kva., 460 volt units, .05 ohms in series with each capacitor.

Arresters: Special high thermal capacity arrester—to break down at 25–35 kv. RMS.

In these tests both high and low voltage capacitors were used for surge reduction. The effect of the high voltage capacitors is strikingly shown by comparing circuit arrangements A, B, C in which only low voltage capacitors were used, with circuit arrangements D, E, F, G, in each of which the high voltage capacitor was used. The number of surges per day when the high voltage capacitor is used is very much less than when the low voltage capacitor was used as in tests B and C or no capacitor as in test A. It is seen also that about 50 per cent reduction in the average value of the surge is obtained when the high voltage capacitor is used as compared to no capacitor at all. Little evidence was obtained to indicate that high voltage arresters were of any value. (See Table 1.)

Test C—Location: National Alloy Steel Company, Blaw Knox, Pa.

Furnace: One ¼ ton single phase furnace; one 1 ton, 3 phase furnace, both supplied from one 1000 kva., 2300 volt, 3 phase transformer.

Circuit: See diagram, Figure 6.

*"Surge Voltages in Arc Furnaces," Stewart-Hobson-Griscom, *Westinghouse Engineer*, May, 1941.

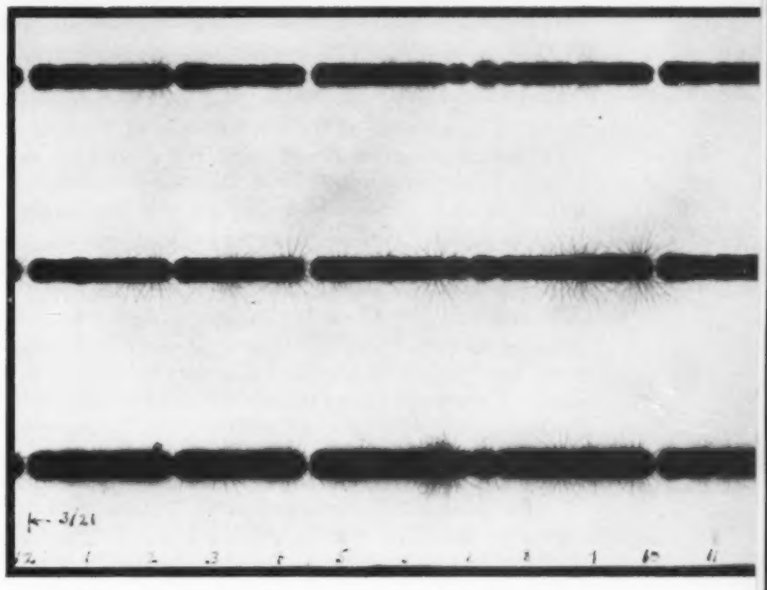
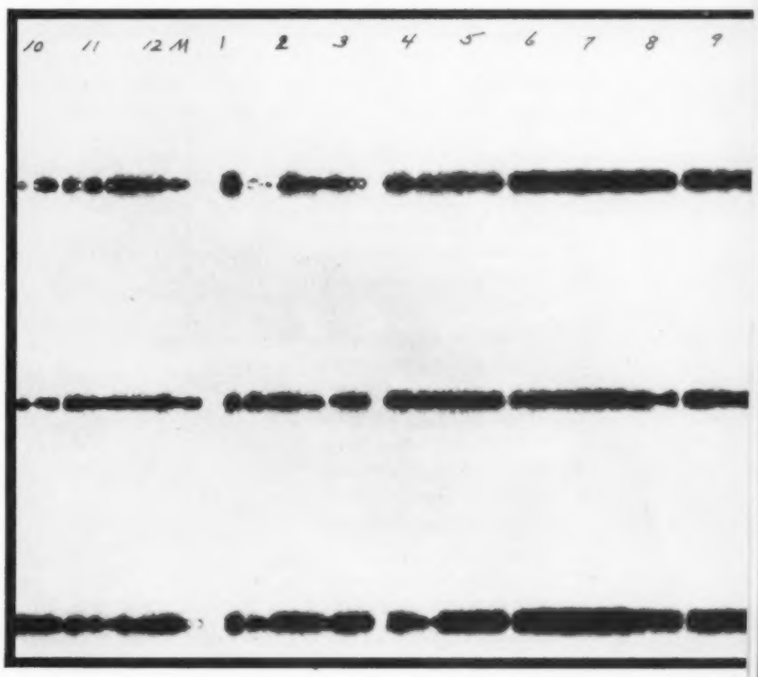


Figure 4—Surge record at Northwestern Steel and Wire Company before the use of surge reducing capacitors.

This small furnace installation is supplied from a 2300 volt, overhead feeder. Three circuit breakers are used, two of them to change the connections on the primary from star to delta, the third being the line breaker. All these breakers are insulated for 25,000 volts. The 1 ton furnace runs only at night, the ¼ ton furnace operates both at night and in the daytime. The test record applies to both furnaces.

Table II is a summary of the tests made in this plant.

Figure 5—Surge record at Northwestern Steel and Wire Company after surge reducing capacitors were added.



It is evident from these tests that size of the furnace or value of incoming line voltage have little bearing on the surges. The crest value of these surges are considerably higher in proportion than on the larger furnaces. The external star-delta breakers and an externally mounted reactor is not usual, but should not contribute to higher surges unless the star-delta breakers were operated without first opening the line breaker. No equipment troubles have been experienced, nor would any be expected since the breakers used here were taken from an old 23 kv. furnace installation.

In this test surge reducing capacitors were tried with striking results. The films show that quite high surges were experienced until the capacitors were installed. Figure 7 shows 17 surges of average value nearly 10 kv. for one day previous to the installation of the capacitor, for the other 6 days on this film there were only 9 surges of average 7 kv. Figure 8 shows the effect of adding a .5 mfd. capacitor. Another run of 7 days with this capacitor shows 16 surges, maximum 5.9 kv., average 5.25 kv. Other tests show a similar reduction in number and magnitude of surges. The capacitor was then removed and the results in the last item in the tabulation showed that the number and magnitude of the surges immediately increased.

Test D—Location: Copperweld Steel Company, Warren, Ohio.

Furnace: One 12,000 kva. 60 cycle transformer; one 25 ton furnace.

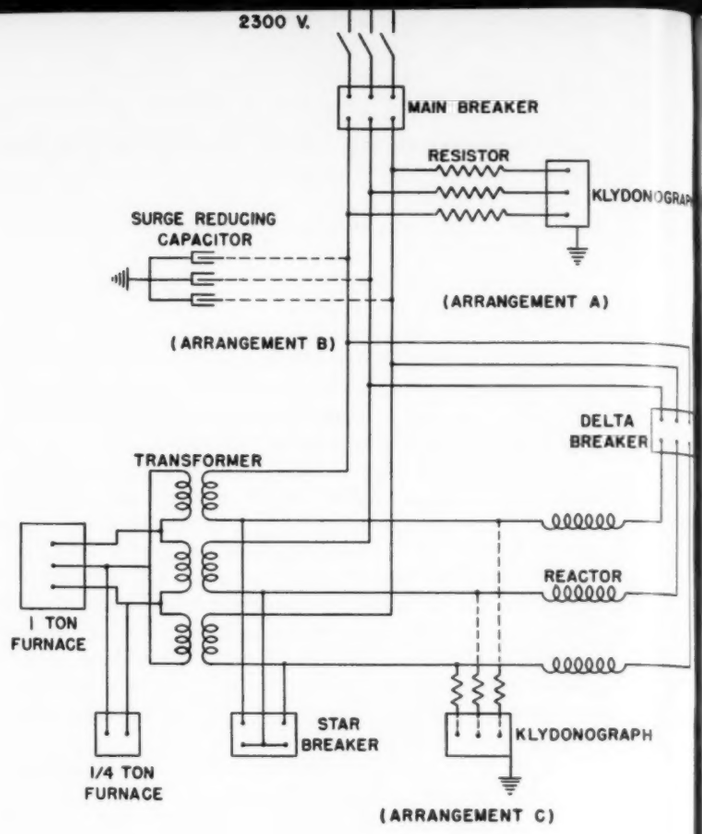


Figure 6—Diagram showing circuit of arc furnaces at National Alloy Steel Company.

TABLE I

Summary of Test Data from Two 7500 Kva. 13.8 Kv. Furnaces Over Period March 20, 1940 to November 1, 1940 (Test B)

Circuit arrangement	No. of surges	Crest kv., highest surge line to ground	No. of surges above 1.75 normal line to ground, volts per day	Average 6 highest surges on each film crest, kv. to ground	Length of test run, days
A. Normal No reactor	218	68	35	44	6¼
B. Low voltage capacitor High voltage arresters No reactor	1024	49	28	38.4	38
C. Low voltage capacitor High voltage arresters 5.9 per cent reactor	2145	58	13	31.1	165
D. High voltage capacitor High voltage arresters 5.9 per cent reactor	17	27	1	22.3	17
E. High voltage capacitor Low voltage capacitor High voltage arresters 5.9 per cent reactor	132	30	3	21.6	44
F. High voltage capacitor Low voltage capacitor High voltage arresters No reactor	295	44	5	27.6	59
G. High voltage capacitor High voltage arresters No reactor	203	28	7	23.8	29

TABLE II

Summary of Test Data from 2300 volt, 1000 kva. Furnace Transformer

No. of surges	No. of surges per day	Crest kv., highest surge to ground	Average of 5 highest surges, crest kv. to ground	Ratio of average to normal	Length of test, days	Circuit arrangement
52	16	9.1	8.15	4.35	3.25	No surge protection.
72	10	13.9	11.65	6.2	7	
50	11	8.6	7.5	4.0	4.5	
91	17	17.5	17	9.02	5.25	
111	18	17.5	16	8.5	6	
17	17	12.1	9.9	5.2	1	No surge protection.
9	2	7.7	7.0	3.7	6	Surge capacitor added.
16	2	5.9	5.25	2.7	7	
10	2	6.3	5.29	2.8	6	Klydonograph between reactor and transformer with surge reducing capacitor.
32	7	11.0	8.51	4.5	4.5	No surge reducing capacitor.

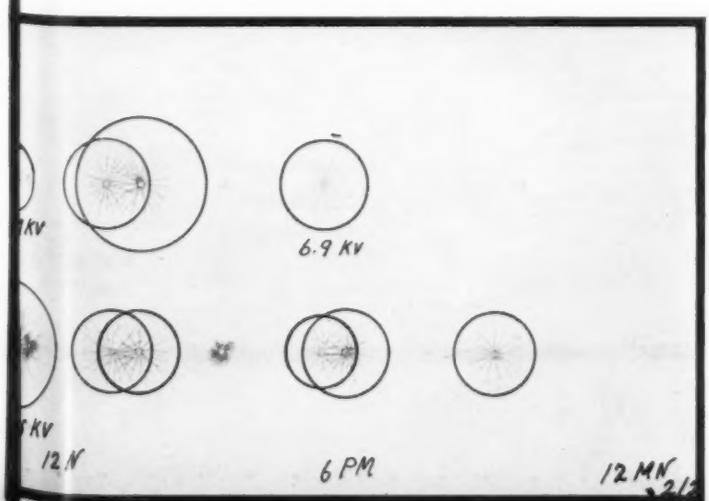
Power supply: 3 phase, 23 kv. outdoor line from Ohio Public Service Company substation ½ mile away.

The number of surges per day in this installation was higher than expected. This was due to the fact that the average number of daily operations of the circuit breaker was also higher than expected. Figure 9 shows a typical surge record at this plant. A careful record of the circuit breaker operations was kept in order to determine its effect on the number of surges.

Test E—Location: Republic Steel Corporation, Canton, Ohio.

Surge tests were made at the Republic Steel Corporation's plant in Canton, Ohio, on two 12,000 kva., 2300 volt transformers, supplying two 50 ton furnaces.

Figure 7—Film record showing surges in circuit of Figure 6 without a capacitor in the circuit.



The 23 kv. line, which supplies these furnaces, comes from the Republic station ¼ mile away and from Ohio Power Company's Sunnyside substation 2½ miles away.

Tests were made at this installation for several reasons.

The first is that this plant is one of the largest, if not the largest, electric furnace installation in the country.

The furnaces in this plant include:

Two 25 ton furnaces, each supplied by 10000 kva. transformer.

TABLE III

Arc Furnace Tests, Copperweld Steel Company, Warren, Ohio

23 kv. line; 13.28 kv. line to ground normal and 18.8 kv. line to ground crest.

No. of circuit breaker trips	No. of surges above 33 kv., line to ground	No. of surges per day	Crest kv. of highest surge, line to ground	Average of 5 highest surges, line to ground	Ratio of average to normal	Length of test days
542	73	10	81.4	60.75	3.15	7
538	45	6	90.5	70.8	3.75	7
539	68	9	81.3	71.8	3.8	7
521	64	9	71.1	67.4	3.6	7
745	145	21	73.2	63.2	3.35	7

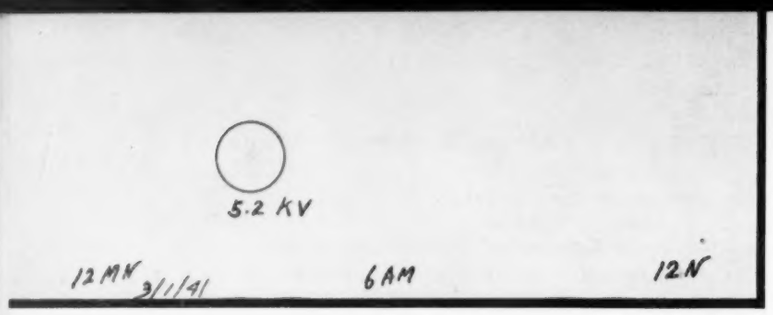
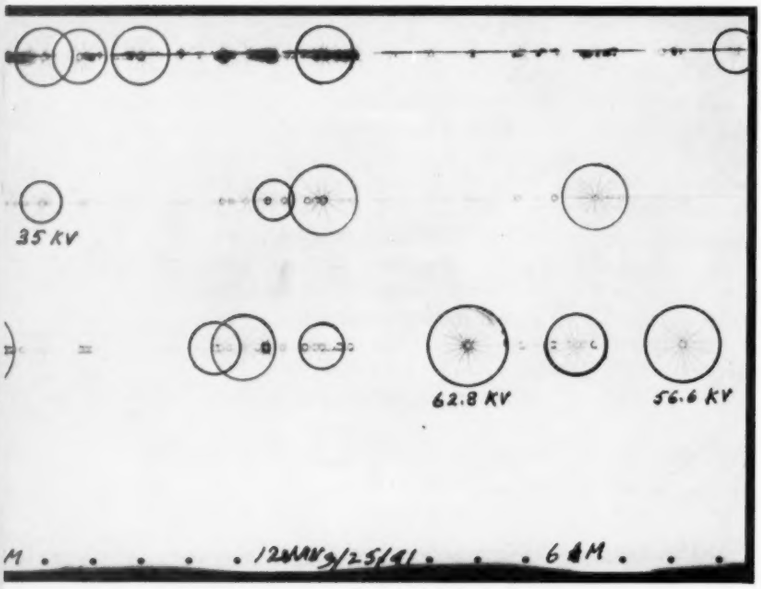


Figure 8 (above)—Film record showing effect of adding .5 mfd. capacitor in circuit of Figure 6.

Figure 9 (center)—Chart showing typical surge record at Copperweld Steel Company.



Three 15 ton furnaces, each supplied by 4500 kva. transformer.

Six 50 ton furnaces, each supplied by 12,000 kva. transformer.

One 7½ ton furnace, supplied by 3000 kva. transformer.

One ½ ton furnace, supplied by 300 kva. transformer.

The second reason is that in this installation, which had been in operation a good many years, there would be considerable experience with troubles due to surges and what steps had been taken to cope with them.

In addition to the day by day record of surges, a set of tests under controlled conditions was made with a specially arranged high speed klydonograph which was equipped with a marker control so that time and operations could be definitely synchronized.

This series of tests include:

(a) Closing on light load, picking up a heavy load, then dropping the load by opening the breaker a predetermined number of times.

(b) Closing and opening the breaker under no-load conditions.

(c) A series of tests to show surges during the melt-down, starting the high speed film when the melt starts.

The results of the controlled tests (a) and (b) are given in Table IV.

As would be expected in a test of such limited extent, the number of surges due to switching under controlled conditions were very few. However, when we consider that in the normal operation of the furnace the breaker is operated a good many more times than was done in this test, the number of surges obtained in these few operations is additional evidence that the majority of the surges are due to breaker operation.

The second question, whether opening load current is more likely to cause surges than opening magnetizing current, cannot be settled since the number of tests is so small. However, as far as these tests go it appears that opening no load gives rise to more surges than opening load current. There are no records of opening short circuits, since there were no short circuits during the test.

Another set of tests with the high speed klydonograph were made to find out whether the majority of the surges occurred during the first melt down period when the swings are heavy but the breaker operations few; or in the refining period when there are few if any swings but the breaker is operated more frequently.

The results of these tests indicate that surges are not caused by the load swings during the melting period.

Figure 10 shows a typical surge record at this plant.

Table V gives the summary of the test results.

Figure 10 (below)—Chart showing typical surge record at Republic Steel Corporation.

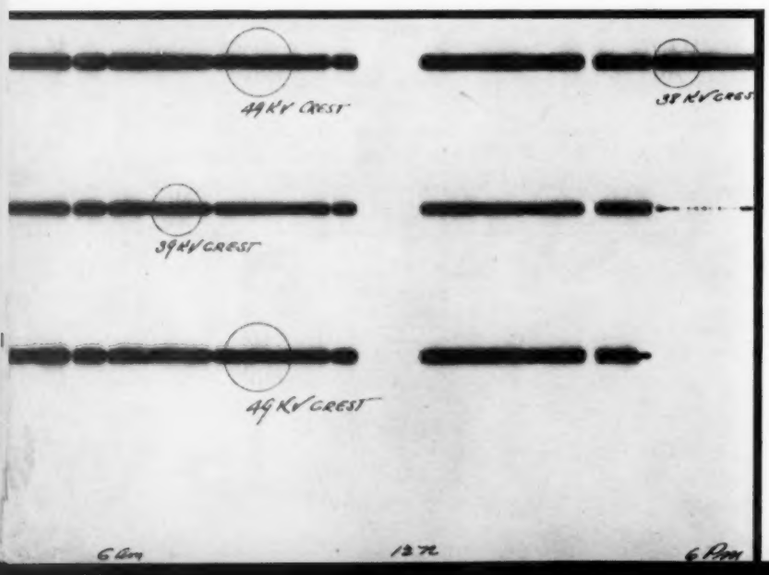


Figure 11—Equivalent circuit of furnace transformer when magnetizing current is opened.

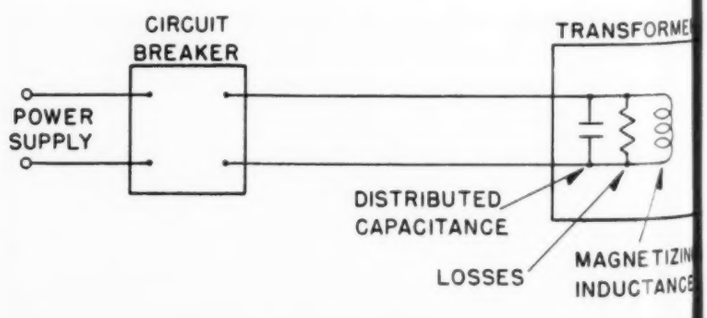


TABLE IV

Summary of Controlled Tests (C) on 50 Ton 12,000 Kva. Furnace

Test No.	Load opened sec. amps.	Surge volts, crest kv. to ground	Ratio, surge volts to normal
4	20,000	38	2.0
13	30,000	44	2.35
14	zero	40	2.13
21	zero	33	1.73
25	zero	50	2.65

13 load tests made and 12 no load tests.
All surges occurred on opening breaker.

COMMENTS ON TESTS

The number of surges per day and the average values of the surges are relatively low in this plant. The ratio of the average surge to the normal voltage varies between 2.2 to 3 times. The number of circuit breaker operations is normal for this type of service.

Experience in the operation of electric furnaces in this plant has resulted in the adoption of the following standard practices:

(1) 34.5 kv. insulation is used throughout on the 23 kv. arc furnace circuits for breakers, insulation and cable.

(2) The furnace breakers are automatic from time delay overcurrent relays on the primary side. Grounds or failures on the high tension insulation operates instantaneous current trip relays on the back-up breakers of large interrupting capacity.

(3) Outdoor type 34.5 kv. oil circuit breakers with ample volume of oil are used for both backup and furnace breakers.

(4) Oil is tested and filtered every two weeks if necessary.

(5) Switching of the transformers is done by first running the electrodes up, then operating the circuit breaker. This is done to reduce, as much as possible, deterioration of the oil due to arcing.

Trouble-free operation has been obtained on these furnace circuits largely because of these precautions.

CONCLUSIONS

The series of tests presented covers a sufficient variety of arc furnace installations to permit drawing some conclusions. Every installation tested gives evidence of numerous surges some of them quite high in value. Two questions are certain to be asked; one is, what is the cause of these surges? The second is, what should be done about them?

These surges occur at random and therefore tests must be carried out for a long period of time to definitely establish the causes. The difficulty of correlating the surges to either a furnace operation or a switching operation is obvious. Unless this correlation is exact we cannot say positively that every surge is due to switching. However, both test and theory lead to the conclusion that the majority of the surges are caused by the opening of the breaker.

Tests show that when the magnetizing current of the transformer is opened by a circuit breaker, it is possible to get transient overvoltages. The magnitude of this transient depends on:

1. The point in the wave at which the circuit is opened.
2. The characteristics of the transformer circuit.

In considering these transients from a theoretical standpoint, the circuit when the breaker opens can be reduced to the equivalent circuit shown in Figure 11. This consists of a magnetizing inductance, a capacitance representing the effective distributed capacity of the windings to ground, and an equivalent resistance representing the losses due to the magnetizing current.

The opening of the breaker disconnects the power system, preventing further flow of current from that source, but leaves the stored energy in the disconnected circuit. The arc formed when a circuit breaker opens

TABLE V

Summary of Test Data from Two 50 Ton, 12,000 Kva., 23 Kv. Furnaces Over Period December 4, 1940 to February 1941 (Test C)

No. of surges	Crest kv. highest surge to ground	Average of 5 highest surges on each film crest, kv. to ground	Ratio of average to normal	Length of test, days	No. of surges per day	Average number of breaker operations per day
57	47	43.2	2.3	11	5	72
66	71	47.2	2.5	13.5	5	62
44	55	42.2	2.2	14.5	3	35
63	72.5	52.8	2.8	13.25	5	52
100	64	52.8	2.8	16	6	48
24	59	55.1	2.9	8	3	50

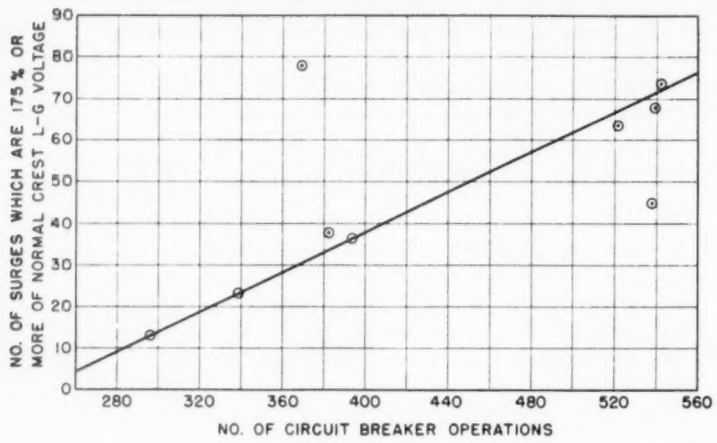


Figure 12—Curve showing relation between breaker operations and number of voltage surges.

has a natural tendency to go out when the current goes through zero. The efficiency of oil and air circuit breaker operation depends on this fact. However, in practice circuit interruption for one reason or another does not always take place at current zero. This is technically called forcing current zero. When this happens there will be electromagnetic energy stored in the inductance of the transformer circuit, which will cause a voltage transient governed by the familiar relation:

$$\tfrac{1}{2}Li^2 = \tfrac{1}{2}Ce^2$$

The capacity of the transformer windings to ground is quite small, so that the value of e may be quite large to satisfy this equation and in some cases will exceed the system voltage to which it bears no relation.

It is interesting to note that, when a capacitance which is large compared to the capacitance of the windings, is purposely connected between the transformer and the circuit breaker, the surge voltages are materially reduced as the tests recorded will show. Another significant test that supports this theory has been made with two klydonographs, one on the system supply side of the breaker and the other on the transformer side of the breaker. The results showed no surges whatever recorded on the klydonograph on the system side of the breaker, and the usual number of surges on the film which was connected on the transformer side of the breaker. Figure 12 also substantiates this argument, as it shows that the number of surges increases in proportion to the number of circuit breaker operations.

The answer to the second question what should be done about the surges will depend on the particular installation and the following conditions.

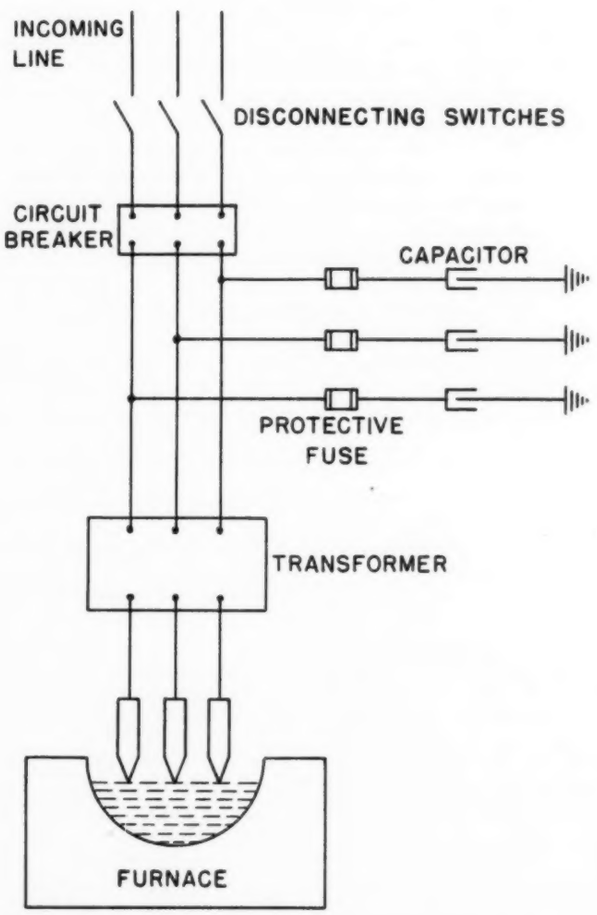
1. The ratio between the service voltage and the insulation rating of the equipment. That is to say the margin of over-insulation.
2. The number of surges above a given value over a long period of time.

It is known that the effect of surge voltages above a certain value on insulation is a cumulative one. The initial factory test of impulse strength is only a rough measure of the life of the insulation when subjected to repeated surges.

Experience has shown that the switching equipment and transformers used in arc furnace installations have had a sufficient margin of insulation strength even in cases where the service voltage was the same as the rating of the equipment. The failures of insulation directly due to surges have been relatively few, though quite high surges have occurred in many installations without any one knowing about it. On the other hand, the use of surge reducing equipment, the value of which has been clearly demonstrated, should be advantageous in two ways. First, it will reduce the magnitude and number of the surges bringing them below the value at which repetition would have any effect on the insulation.

Second, it will give an additional factor of safety for those installations where the policy of over-insulating is followed. This practice of over-insulation to increase insulation resistance to conducting dust, is quite familiar to the steel industry and its advantages are well established. For arc furnace installations it has the addi-

Figure 13—Schematic diagram of surge protective equipment on arc furnaces.



tional advantage of increasing the insulation resistance to surge voltages.

As a result of these tests it may be stated that either surge reducing equipment or over-insulation would be desirable in any installation. The combination of both over-insulation and surge protection can be justified in some cases for the following reasons:

1. The investment is small compared to the expense and the loss of production which may be caused by an insulation failure.
2. The dust and dirt in most installations make it important to have a sufficient margin in the insulation, aside from the surges.

In cases where the service voltage and the rated insulation voltage are nearly alike, the importance of reducing the surges is obvious and the necessity is greater.

DISCUSSION

PRESENTED BY

J. E. HOBSON, *Central Station Engineer,* Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pennsylvania

C. M. FOUST, General Engineering Laboratory, General Electric Company, Schenectady, New York

L. S. STEINER, *Electrical Superintendent,* Timken Roller Bearing Company, Canton, Ohio

SAMUEL ARNOLD, 3rd, American Bridge Company, Pittsburgh, Pennsylvania

E. W. BOEHNE, General Electric Company, Philadelphia, Pennsylvania

B. M. JONES, *Planning Engineer,* Duquesne Light Company, Pittsburgh, Pennsylvania

C. C. LEVY, Industry Engineering Department, Metal Working Sales, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pennsylvania

J. E. HOBSON: The authors have conducted a well organized series of tests and have made a careful analysis of the test results. The data is of particular interest since it contributes further evidence regarding the existence and magnitude of over-voltage surges, and clearly demonstrates that capacitors on the high voltage side of the furnace transformer are quite effective in reducing the magnitude and number of the surges. The results presented in this paper substantiate the experience obtained at the Northwestern Steel and Wire Company (field data recorded in Table I) where high voltage capacitors have been in satisfactory operation for more than a year without any evidence of the over-voltages experienced prior to their installation.

At the conclusion of the Sterling field tests early last fall, laboratory tests were started to determine the nature of the surges, their source, and to check schemes for controlling their magnitude and frequency-of-occurrence. Carefully designed and constructed model transformers with suitable synchronous switching equipment have been used in the investigation. It is expected that the laboratory data will be available for early publication.

Results of the laboratory investigation so far substantiate the theory outlined by Messrs. Whitehouse and Levy, that the surges originate principally from the collapse of magnetizing flux in the transformer at the time of primary circuit interruption. We have also found that some surges of smaller magnitude accompany collapse of the transformer leakage flux, and a few surges undoubtedly originate from fluctuations of the furnace arc. However, the surges appearing on the primary circuit originating from fluctuations of the arc, are quite small. Consequently, it appears that the interruption of transformer magnetizing current at other than zero-current accounts for those over-voltages approaching dangerous values. This theory is substantiated by field data from operating furnaces, as reported in this paper and elsewhere, in that the higher surges can be definitely identified with switching operations and the presence of a transformer reactor, decreasing the primary power factor, results in surges of lower magnitudes.

The magnitude of the surge will depend on the point of the magnetizing-current wave at which arc interruption occurs in the primary breaker. Laboratory results and theoretical considerations indicate that surges ten to fifteen times normal can occur when the magnetizing current is interrupted near its crest.

It seems likely that surges occurring following the interruption of load current on the primary may be higher than surges resulting from the interruption of magnetizing current alone, since for high power factor loads the transformer magnetizing current component of the total current will be near maximum at the time the total current is zero. Breakers tend to interrupt near a current zero, so that the magnetizing current (and, consequently, the transformer flux) will be greater at the time load current is interrupted than when exicting current alone is interrupted. We may thus expect higher voltage surges on furnaces where it is not the practice to lift electrodes before opening the primary breaker for switching operation, or where there are a number of automatic breaker operations.

Surges will not accompany every breaker operation, even when interrupting load current, since the furnace arc will not extinguish in all cases simultaneously with extinction of the primary current. If conditions of the arc, electrode spacing above the charge, etc., are such that the arc is maintained after the interruption of primary current, the energy stored in the transformer will be dissipated through the arc without the formation of high surge voltages. Surges originating from this phenomena will occur when primary (breaker) and secondary (furnace arc) currents interrupt at the same time. This is more likely to occur with the furnace operating at a high power factor. It can be expected that the percentage over-voltage experienced with the higher voltage transformers will be less than the percentage over-voltage experienced with lower supply voltages, since the ratio of inherent transformer capacitance to

magnetizing inductance increases as the supply voltage increases.

This phenomena is not unique to arc furnace transformers, although far more likely to occur with a furnace transformer. A few cases of high surge voltages resulting from the interruption of magnetizing current on large power transformers are known. It is unusual with power transformers, however, since appreciable circuit capacitance is usually connected, absorbing the transient energy, and since breakers seldom interrupt magnetizing current far enough from a current zero to create appreciable over-voltages. The situation of circuit interruption simultaneously on primary and secondary is not encountered with power transformers under load, since the secondary circuit usually remains established.

The laboratory tests fully substantiate the beneficial effects of shunt capacitors added to the transformer primary terminals, and have demonstrated that the microfarad values recommended for general application are correct.

I would like to emphasize that the surges are not created by faulty breaker operation, but are a natural consequence of correct circuit breaker action. Furthermore, it has been observed that the surges are independent of breaker arcing time and of the type of breaker used. Surges attendant with air breaker operations appear to be somewhat lower than those attendant with oil breaker operations since the air breaker has less tendency to force a current zero.

C. M. FOUST: As a part of the work of the subcommittee set up for the purpose, surge voltages present in arc furnaces have been the subject of a coöperative study conducted by our company and interested furnace operators and power companies. Organizations which are taking part in this committee study are:

Rotary Steel Company of Detroit, Michigan
Detroit Edison Company of Detroit, Michigan
Atlas Steel Company, Ltd., of Welland, Ontario
Crane Company of Chicago, Illinois
Eastern Malleable Iron Company of Naugatuck, Connecticut

Also other and prior studies have been made by the Bethlehem Steel Company, several public utilities, and our company.

This discussion pertains to the committee investigation in which it is intended eventually to include both large and small furnaces as well as single phase and three phase installations. Also equipments were selected for study when possible where electrical operational difficulties had been encountered.

As the surge voltage recorder* is convenient of application and will operate over several days time unattended, it was selected to make the initial survey. This instrument records surge voltages on photographic film as illustrated in Figure 1 by means of positive polarity Lichtenberg figures. It is a single phase recorder which fact provides for the separation of phase records, thereby eliminating spurious induced surge voltages from conductors other than that on which the measurements are being taken. The use of positive Lichtenberg figures only, avoids the use of the negative figure for measurement purposes which is objectionable because of variation in figure size and wave shape as well as crest voltage. Negative figures are also only one-third to one-half the use of positive figures and negative surges, therefore, may be lost in large positive records which overlap them. In considering Lichtenberg figure records it is well to bear in mind that an average figure size deviation of plus or minus 20 per cent is obtained. This then is the order of accuracy obtained for any single measurement.

Our measurement program is not completed and final conclusions from the data are not as yet available. However, the summary which follows indicates the trend of the records being obtained.

ROTARY STEEL COMPANY OF DETROIT

Because some interruptions to furnace service apparently due to flashover of the transformer secondary buses had occurred at the Rotary Steel Company, a program of surge-voltage measurement was arranged through the coöperation of the Rotary Steel Company and the Detroit Edison Company.

The two arc furnaces on which measurements are being made are each supplied with power through a 10,000 kva. 3-phase transformer rated 24,000 volts primary to 240 volts secondary at 60 cycles per second.

The surge voltage recorders on the primaries for line to ground measurements were connected to the high voltage lines of the transformer through voltage dividers with ratios of 8 to 1. These dividers are made up of standard transmission suspension insulator disks of 10 in. diameter. On the secondaries the surge voltage recorders were connected between the low voltage transformer buses and ground through capacitors rated 2500 volts and having 2 microfarad capacitance. The surge recorder capacitance is 25 micromicrofarads and the secondary recorders are, therefore, direct reading.

Line to ground surge voltages on the primaries of both furnaces are summarized as to amplitude in the accompanying table.

These data show line to ground measurements ranging up to 71 kv. or 3.6 times normal crest to ground, at which level only one surge occurred during the 250 hr. measurement run. The second highest surge voltage was below 50 kv. or 2.5 times normal.

These primary surge voltages are well within the range of times normal voltages commonly experienced for switching surges. For instance, a curve* also obtained from surge voltage recorder data and on high voltage lines is summarized as follows:

Times normal	Percentage exceeding
2	57
3	23
4	6
5	2
5.5 maximum amplitude	

A crest voltage of 71 kv. is sufficient to flashover on

*"Instruments for Lightning Measurements," C. M. Foust, *General Electric Review*, April, 1931

*"Lightning Investigations on Transmission Lines II," Lewis and Foust, A.I.E.E., 1931, Fig. 1.

impulse voltages, between ½ in. square rods, a gap of 2.4 in. under standard conditions of temperature, pressure and humidity. A 60 cycle crest voltage of this level will flash over about 3 in. of rod gap.

During the measurement run of Table I surge recording equipment was also connected, line to ground, on the secondary of furnace No. 1 with a threshold of crest voltage measurement of 1.7 kilovolts. No surges were recorded. Secondary lightning arresters were in use at this time, connected line to ground, and expected to operate at 1.5 kv. crest.

Seventy-two per cent of all surges were single phase, 26 per cent two phase, and 2 per cent three phase.

Measurements made between the secondary buses and ground are summarized in Table II.

The highest voltage recorded was 8 kv. crest. This voltage is sufficient to flashover about ¼ in. of rod gap on 60 cycle voltages and something less than this on switching surges and impulse voltages. Therefore, while 8 kv. on a 240 volt secondary represents a 40 to 1 times normal voltage, it is not high enough to be hazardous to power equipment insulation. Standard impulse voltage test levels for this insulation class range 30 kv. and above.

ATLAS STEEL LIMITED OF WELLAND, ONTARIO

At the Atlas Steel Company several transformer winding failures have been experienced and surge voltages are being measured on two equipments herein designated furnace No. 1 and furnace No. 2. The first transformer rating is 1200 kva., 4150 volts primary and 225 volts secondary, and the second 4000 kva., 4000 volts primary and 235 volts secondary, both 3 phase and 25 cycles per second. Measurements have been completed as follows:

Furnace No. 1

Line to ground voltages

1. Primary buses to ground
2. Reactor-transformer tap point to ground

Line to line voltages

3. Between primary buses

Furnace No. 2

Line to ground voltages

4. Primary buses to ground

Line to line voltages

5. Between primary buses

For these measurements surge recorder voltage dividers with a ratio of 1.66 to 1 and for the line to ground and 3 to 1 for the line to line were used.

Line to ground surge voltages on furnace No. 1 are summarized in Table III, which shows all voltages below 12 kv. (3.5 times normal) based on 3380 volts normal crest to ground.

In Table IV are summarized line to ground voltage measurements with connections made at the terminals of the transformer windings excluding, therefore, the series reactors. These voltages range somewhat higher than the bus voltages but still are all below four times normal crest voltage.

In Table V are summarized line to line surge voltages all of which ranged below 2.7 times normal.

Table VI classifies line to ground surge voltages on furnace No. 2. For this transformer two surges occurred

TABLE I

Line to Ground Surge Voltages

(250 hour run)

Voltage range, kv. crest	Times normal crest to ground, ratio	Number of surges	
		Furnace No. 1 primary	Furnace No. 2 primary
25 through 30	1.3–1.5	42	71
30 through 35	1.5–1.8	16	30
35 through 40	1.8–2.0	3	18
40 through 45	2.0–2.3	0	6
45 through 50	2.3–2.5	0	3
50 through 55	2.5–2.8	0	0
55 through 60	2.8–3.0	0	0
71	3.6	0	1

TABLE II

Line to Ground Surge Voltages for Furnace No. 2 Secondary Voltages

(1044 hour run total)

Transformer primary	Transformer secondary	
	Voltage range, kv. crest	Number of surges
Many surges similar to Table I in amplitude and reaching a maximum of 64 kv.	1.7 through 2	36
	2 through 3	17
	3 through 4	7
	4 through 5	2
	5 through 6	0
	6 through 7	1
	7 through 8	1

TABLE III

Line to Ground Surge Voltages

(84 hour run)

Furnace No. 1

Voltage range, kv. crest	Times normal crest to ground, ratio	Number of surges, primary
6 through 8	1.8–2.4	48
8 through 10	2.4–3.0	16
10 through 12	3.0–3.5	3
12 through 14	3.5–4.1	0

in the neighborhood of five times normal to ground giving a crest value of 18.3 kv.

The line to line surge voltages for furnace No. 2 are summarized in Table VII. The voltage values all ranged below 22 kv. and 3.7 times normal. The regular impulse test levels for power and distribution transformers in this voltage rating are 76 kv. and above. The low frequency test is 19 kv. rms. The recorded surge voltages, therefore, do not approach the range of levels which might be considered hazardous to apparatus or circuit insulation.

During the measurements of Table VII surge recording equipment was also connected, line to ground on the secondary winding, with a threshold crest voltage of 1.7 kv. No surges were recorded. The surges are, therefore, below this threshold level.

At the Crane Company in Chicago and the Eastern Malleable Iron Company of Naugatuck, Connecticut, experimental studies are being made of single phase furnaces. The data obtained and analyzed are, however, not sufficiently complete to warrant presentation and definite conclusions.

A paper summarizing studies similar to those described above and written by L. W. Black and E. W. Boehne was presented at the Philadelphia meeting of the Association of Iron and Steel Engineers, December 2, 1939. (See IRON AND STEEL ENGINEER, September, 1941.)

It is expected that these measurements will be continued until it has been definitely demonstrated that surge conditions in arc furnace apparatus and circuits either are or are not of sufficient magnitude to be hazardous to the operation of the equipment. The data contained in this discussion are believed to be sufficient to indicate the general levels of surge voltage amplitudes. Further study of records already available and possibly the securing of additional records wherein wave shapes and corresponding time of occurrence in primary and secondary can be studied will provide for more definite conclusions. At the present, however, it seems quite reasonable to state from the data contained in this discussion that the following conclusions will hold.

1. Surge voltages on both transformer primary and secondary are caused by switching operations and by abrupt furnace current variations.
2. Surge voltage levels normally present in arc furnace circuits are not excessive when compared to those commonly encountered in power circuits and are not of a level hazardous to apparatus and circuit insulation.
3. Of switching surges some 72 per cent are single

TABLE IV

Line to Ground Surge Voltages (84 hour run) at Reactor—Winding Connections

Furnace No. 1

Voltage range, kv. crest	Times normal crest to ground, ratio	Number of surges
6 through 8	1.8–2.4	29
8 through 10	2.4–3.0	9
10 through 12	3.0–3.5	2
12 through 14	3.5–4.1	4
14 through 16	4.1–4.7	0

TABLE V

Line to Line Surge Voltages (84 hour run)

Furnace No. 1

Voltage range, kv. crest	Times normal line to line, crest voltage	Number of surges
10 through 12	1.7–2.0	6
12 through 14	2.0–2.4	2
14 through 16	2.4–2.7	1
16 through 18	2.7–3.3	0

TABLE VI

Line to Ground Surge Voltages

(184 hour run)

Furnace No. 2

Summary of phase 1 to ground only

Voltage range, kv. crest	Times normal line to ground, crest voltage	Number of surges
6 through 9	1.8–2.4	31
8 through 10	2.4–3.0	16
10 through 12	3.0–3.5	8
12 through 14	3.5–4.1	3
14 through 16	4.1–4.7	0
16.6	4.9	1
18.3	5.4	1

TABLE VII

Line to Line Surge Voltages (168 hour run)

Furnace No. 2

Voltage range, kv. crest	Times normal line to line, crest voltage	Number of surges
10 through 12	1.7–2.0	24
12 through 14	2.0–2.4	4
14 through 16	2.4–2.7	4
16 through 18	2.7–3.1	0
18 through 20	3.1–3.4	2
20 through 22	3.4–3.7	1

phase, 25 per cent two phase, and 2 per cent are three phase.

In the collection, tabulation, and study of these data considerable contribution has been made by members of the companies already mentioned. Particularly in the work of servicing the instruments under the difficult situations encountered, very capable assistance has been rendered. In closing, therefore, I wish to thank all who are participating in this study for the earnest and constructive coöperation being rendered.

L. S. STEINER: There are several factors which have not been brought out which I believe have a definite bearing on this problem.

The data given have not taken into account the voltage tap these transformers were connected to when the surges occurred and which I believe have a definite relation to the magnitude of the surges produced, particularly by switching. (I am assuming the transformers discussed are multi-tap transformers.)

I am basing this opinion on our own experience at Timken some 12 or 13 years ago when we had an epidemic of breaker failures, one of which was particularly disastrous as the fire which followed destroyed the control panel along with other equipment. This was before the days of tap-changers, at least before we had any of them, and all switching was done by breakers.

Our system operates at 22 kv. and at that time we did not use a line breaker, operating all delta tap breakers, inside the delta, and the necessary wye breakers. These particular breakers were insulated for 22 kv. and were of a very low interrupting capacity.

A surge recorder was installed to attempt to find the cause of these breaker failures. The surges recorded were, without exception, much greater when the transformer was connected for the high secondary voltage and were recorded as high as 100 kv.

As far as we were able to determine, all of our breaker failures occurred when opening the transformer magnetizing current only and when connected to the tap giving the highest secondary voltage.

We then revised our breaker set-up, installing breakers of higher interrupting capacity, insulated for 37 kv., including a line breaker, interlocked so that all the tap switching is done with the line breaker open. The more recent installations have of course been installed with motor-operated tap changers operated in conjunction with a line breaker.

Since this time we have had no failures or trouble of any kind which might be attributed to excess surge voltages and I for one strongly recommend the practice of over-insulating all equipment for service of this nature rather than complicate the installation by the use of auxiliary equipment which may be a potential source of trouble.

As far as flashovers on the secondary side of a transformer of this class due to surges are concerned, we have had no experience and it is hard for me to see why this should happen in a well-designed transformer.

As to the reasons for the difference in surge voltages on the various taps, it seems to me that the degree of saturation or possibly the length of the extended winding might have some effect and I would like to hear from some of the transformer designers in regard to this.

We have had no indication of any destrucitve surges due to any cause other than switching and if they do exist are apparently of insufficient magnitudes to cause any trouble.

SAMUEL ARNOLD, 3RD: I want to say that we first became interested in the effect of surge voltages at the time of the flash over of the secondary bars at the Rotary plant. We have come to the conclusion that what Mr. Steiner says is just about right. That is, over-insulate as far as possible and in cases where it is not possible or where the equipment becomes too expensive, add some capacitors as a safety measure.

There is one other item I would like to mention and that is in connection with the steel furnace that had a transformer failure. I believe they listed two or three failures. There were actually five failures and I was present when the transformer core was pulled out after the first. This was definitely mechanical and the transformer had been operating for eleven years without any trouble. This at from 25 to 30 per cent overload. The transformer was rewound locally and failed again just after being put in service; then it was rewound the second time and failed. The third time just before it was put in service, someone found a pipe wrench on top of the core, together with a few nuts, so I came to the conclusion that there was some very careless workmanship. The last time it was rewound, they apparently did a good job for it is running today.

I agree with Mr. Foust in his statement that these surge voltages are not serious, and are of no greater magnitude than switching voltages normally obtained on large distribution transformers.

E. W. BOEHNE: The three-phase protective shunt capacitor which was installed at the Bethlehem plant of the Bethlehem Steel Company in 1939 has now been in service almost two years. No trouble has arisen from the original complication due to surges of 70 kv. which were measured at that point. Other capacitor installations followed the initial installation at this plant.

Fundamentally, I believe this surge phenomenon to be a current generated surge, that is, created by the sudden interruption of a small current. If this is true (the data presented here tends to confirm this opinion), I feel that it should be pointed out that the phenomenon is then practically independent of the circuit voltage. It follows therefore that the higher voltage installations are going to be less hazardous whereas the lower voltage installations are more likely to experience a higher "times normal voltage."

The observations seem to confirm my personal viewpoint that (1) more overvoltage stresses have been experienced on furnace circuits with lower primary voltage than on those with higher primary voltage; (2) over insulation of these lower voltage primary furnace circuits has proven a wise investment and (3) capacitor protection of the lower voltage installations when properly applied seem justified as a means of holding the surge to safe levels.

Although the presentation of surge data on a "times normal voltage" basis has its merits provided the primary circuit voltage is at hand, the warning should be posted not to quote these over-voltages entirely in terms of the "times normal primary voltage" without regard to the primary operating voltage. Such a practice would tend to be misleading, forming a too opti-

mistic viewpoint for the low voltage circuits or a too pessimistic viewpoint for the high voltage installations. Until more is known of the phenomena the safest criterion is the absolute magnitude of the surges found.

B. M. JONES: I have just recently made a careful search of the failures of arc furnace transformers on our system here in Pittsburgh, for the last 10 or 12 years, and can find no record of any flashovers from these causes on our old or new furnace transformers. Of course, there may have been some such cases, but since the customer owns the transformer, these may have been corrected without our knowledge. Not that the customer must necessarily tell us anyways, but if there had been repeated cases from a questionable cause, or if such had taken place on large transformers, we probably would have heard about it.

However, this in no way means that we will not encounter them in the future, for, as we all know, there are more and more furnace transformers being installed, and since the authors have shown that there are such cases of failure around the country, it is most natural to expect that we will get our share of them unless a solution to these difficulties is found and put into effect. Also, maybe newer installations are not vulnerable to failures from this cause. Basically, it is true that as the greater number of such transformers are installed, the greater is the chance of failure, unless our manufacturers can build them and provide the necessary protection so that they will not fail.

The effort to correlate voltage surges with the switching operation and the furnace operation should be pursued diligently, as there may be some helpful clues produced.

Relative to the high voltage capacitors being definitely more effective than the low voltage capacitors, the authors point out that the number of surges above a given value were very much reduced. I am wondering if the very last clause means that the number of surges were reduced in number, or that the magnitude of a number of them was reduced, *viz.*, just "cut off the top."

I am particularly interested in the authors' statement that very little evidence was obtained to indicate that the high voltage arresters were of any value, for one of the first things we think of in connection with flashover, is installing some kind of arrester in the proximity of the point of flashover, *viz.*, on the high side, if that is where the flashover is, etc. Obviously, these tests show this, but I am wondering if the authors can explain it.

Republic Steel Corporation furnaces are listed, totaling 13, with 11 of them being quite large. Along the lines of the law of averages, I am wondering if the authors would care to comment on the possible effect of two arcs or of two switching operations occurring simultaneously to produce greater surge voltages at their own individual locations or back at the supplying substation. Obviously, the greater the number of furnaces in operation in a plant, the greater the chance of their striking together, etc.

I hesitate to raise the question, but the fact is that over-insulation is being used right along, particularly where there is lots of dust and dirt, and, very particularly, around steel mills. I am wondering if the fact that we have not encountered more of this flashover of furnace transformers is due to this very reason: over-insulation. If so, maybe the good old practice of buying over-insulated equipment is the solution. We all know the story of buying equipment that will be subjected to knife-edge limitations, that is, repeated surges up to its absolute limit will, over a period of time, have serious effect on insulation; whereas by over-insulating, such surges have less effect. Maybe this is an economical thing to do. True, we should investigate any surge reducing equipment, and get the overall economies of it compared to that of the over-insulated unit itself. But such devices might require considerable maintenance, repairs, and necessitate outages to the furnace itself, which might show up on the red side of the ledger. These two points were brought out in Table VI, and I just want to echo them.

C. C. LEVY: Mr. Hobson makes the point that the surges following the interruption of load current on the primary, may be higher than surges resulting from opening magnetizing current only. While this may be true, it is well to remember that surges will occur when opening under load, only if the furnace arc extinguishes simultaneously with extinction of the current on the high tension side of the transformer. This condition is very unlikely to occur when conditions of the arc are considered, and the fact that interruption of load seldom occurs at high operating power factor. When these points are considered, it still remains that the majority of surges occur on the opening of magnetizing current, and if they occur when opening load currents, the conditions would be such that there is no secondary circuit for dissipation of the stored energy.

Mr. Foust's discussion presents results of tests made by him of a similar nature to those reported in the paper. The order of magnitude of the surges recorded and the average value is somewhat below in some cases and about the same in other instances. The general conclusion of his discussion is that surge voltage levels in furnace operation are not excessive when compared to those usually met in power circuits. While this is undoubtedly true in many cases, it is still also true that the methods of operation, namely frequent switching and opening of the magnetizing current of the transformer, are not used in ordinary power circuits. Furthermore both of these practices conduce to frequent transients in the circuit. I think that some weight should be given to the frequency of this phenomenon as compared with the usual power circuits and also to the random nature of the surge value which depends on the point in the wave at which the circuit is opened.

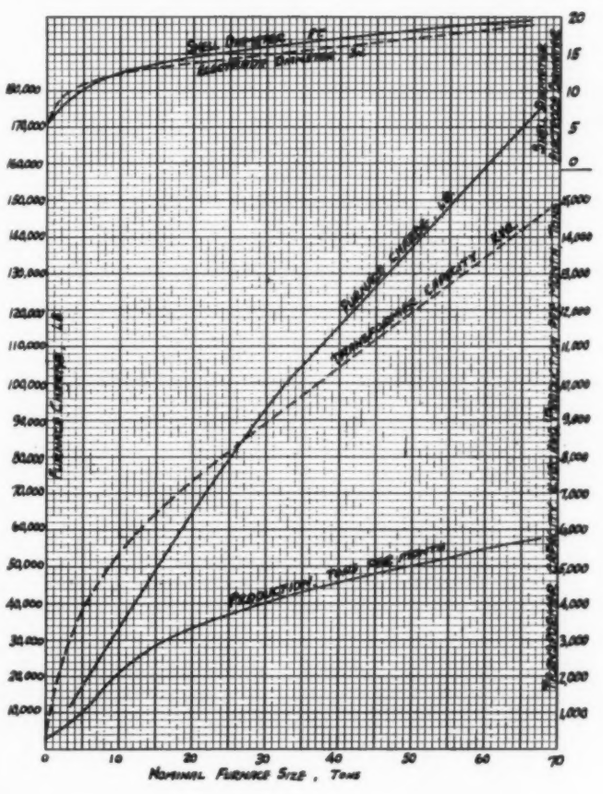
STEEL-MAKING ELECTRIC FURNACES *of the United States*

By T. J. Ess

▲ THE proportionate increase in electric furnace productive capacity during the past two and one-half years indicates the extremely rapid advance in the use of products manufactured by this method. At the start of 1939, electric furnace capacity in the United States was estimated at about 1,550,000 tons per year. One year ago, annual capacity estimates averaged about 2,500,000 tons. The present capacity (including several furnaces under construction) may be taken as over 4,100,000 tons per year, and further expansion is under consideration. A major factor in this phenomenal growth is the demand for air-craft steels, armor plate, and similar products.

In view of the great interest evidenced in the electric furnace expansion, the accompanying tabulation of electric furnaces was compiled. In preparing this tabulation the attempt was made to include the steel-producing units other than those used for the production of castings, ferro-alloys, etc. In some cases the decision as to whether certain units should be included or not was complicated by the uses to which the units were put. An example of this is the Ford Motor Company, where the furnaces are used for widely varying purposes. Those listed in this table for the Ford plant are in the steel foundry; furnaces in the plant's iron foundry are not included. As previously stated, the tabulation includes several furnaces which are still under construction. The omission of a number of the very small furnaces installed does not seriously affect the capacity figures.

Nominal furnace sizes, as listed, may be very misleading, as in practically every case, furnace charges exceed nominal ratings by 30–50 per cent, and even 100 per cent in the case of the smaller furnaces. The largest furnaces among the later installations are nominally rated at 70 tons, but actually take charges of about 90 tons. The nominal sizes are tabulated as reported in general usage by the various companies, and do not represent holding capacity or production rate.



In modern practice, transformer capacity ranges from 600 kva. for the nominal ½ ton furnace up to 15,000 kva. for the 70 ton furnace, or from 600 kva. to 170 kva. per ton of furnace charge, the values decreasing as furnace size increases. Transformers for this service are oil-immersed and water-cooled, and are provided with motor-operated secondary tap changers giving 8 or more secondary voltage steps, ranging from about 110 volts to 275 volts. Each transformer application is a special problem, and the design is tailored to suit each particular installation. Circuit breakers designed for a potential rating 50 per cent (or more) greater than the primary voltage of the transformer are usually adequate for the surges commonly encountered in this service.

Furnace electrodes are commonly of graphite, except in some of the older, smaller furnaces. Their diameters range from 4 in. to 20 in., varying with the kva. capacity of the transformer.

Various items of modern electric arc furnace data are plotted against nominal furnace size in the accompanying graph.

Annual capacity of the various installations was estimated from typical conservative full-time performance on double slag heats of high grade steel, with due consideration of probable effect of furnace diameter and transformer capacity. The production capacity will be increased by 50 per cent or more for single slag heats, and will be decreased 25–35 per cent on the "stainless" grades. These capacities are for operation with cold charges only, and may be greatly increased by the use of molten charges, or duplexing, as is done in several cases.

In addition to those listed, plans are under consideration for the installation of some twenty additional furnaces, with a capacity totaling about 1,250,000 tons per year. These plans are largely centered in Timken, Republic, Bethlehem, and Carneige-Illinois, with several other producers on the western coast. These additions to the tabulated list would give a total capacity of almost 5,500,000 tons of electric steel per year.

The larger producers, as taken from the tabulation, are as follows:

	Tons per year
1. Republic Steel Corporation	733,000
2. Ford Motor Co.	474,000
3. Crucible Steel Co. of America Pittsburgh Crucible Steel Co.	455,000
4. Allegheny-Ludlum Steel Corp.	377,200
5. Timken Roller Bearing Co.	345,000
6. Copperweld Steel Co.	230,000
7. Carnegie-Illinois Steel Corp.	204,000
8. Bethlehem Steel Co.	189,000
9. Rustless Iron & Steel Corp.	168,000
10. Rotary Electric Steel Corp.	130,000

It is interesting to note that these ten producers have a total annual capacity of 3,305,200 tons, more than 79 per cent of the country's capacity.

STEEL-MAKING ELECTRIC FURNACES

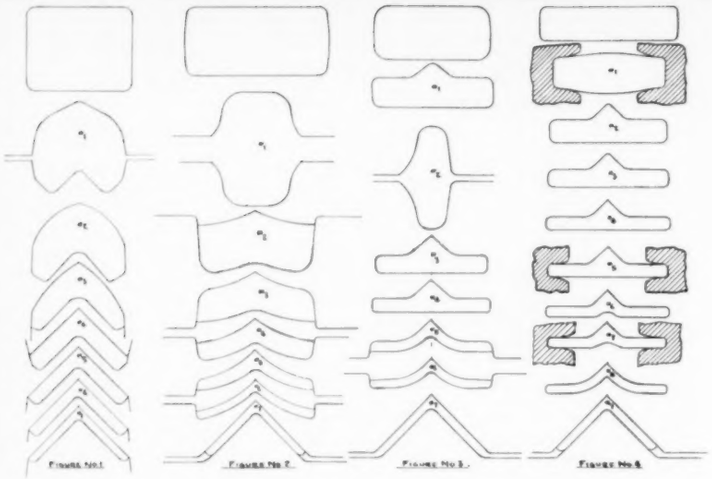
INSTALLED OR UNDER CONSTRUCTION

Company	Location	Number	Nominal size, tons	Approximate shell diameter, ft.-in.	Make of furnace	Transformer capacity, kva.	Diameter of electrodes, in.	Estimated annual capacity, tons
Allegheny-Ludlum Steel Corp.	Brackenridge, Pa.	2	35	16–0	Swindell-Dressler	10,000	18	
		2	25	15–0	Swindell-Dressler	7,500	18	
		2	6	11–6	Swindell-Dressler	3,000	12	
		2	6	11–6	Swindell-Dressler	2,500	12	
		1	6	11–0	Heroult	1,667	12	
		1	¼	....	Swindell-Dressler	175	4	284,000
	Dunkirk, N. Y.	1	15	12–0	Heroult	....	12	
		2	6	11–0	Heroult	....	..	65,600
	Watervliet, N. Y.	2	6	11–0	Ludlum	....	..	
		1	2	8–0	Ludlum	....	..	27,600
A. M. Byers	Ambridge, Pa.	1	15	12–8; 14–8	Heroult	7,500	..	36,000
American Rolling Mill Co.	Middletown, O.	1	6	11–0	Lectromelt	....	..	9,000
Babcock & Wilcox Tube Co.	Beaver Falls, Pa.	1	7½	12–0	Swindell-Dressler	6,000	..	18,000
Bethlehem Steel Co.	Bethlehem, Pa.	2	50	18–0	Lectromelt	15,000	20	
		1	25	15–0	Swindell-Dressler	7,500	18	
		1	6	11–0	Lectromelt	4,000	12	
		4	¼–½	....	Ajax Induction	....	..	180,000
	Steelton, Pa.	1	6	11–0	Heroult	2,000	..	9,000
Braeburn Alloy Steel Co.	Braeburn, Pa.	2	6	11–0	Heroult	1,500 and 3,000	..	18,000
Carnegie-Illinois Steel Corp.	Duquesne, Pa.	1	5	10–0	Heroult	3,000	..	8,000
	Johnstown, Pa.	2	3	9–0	Heroult	1,500	..	6,000
	South Chicago, Ill.	1	60	20–0	Heroult	15,000	20	
		1	30	15–8; 18–0	Heroult	12,000	20	
		3	20	15–8	Heroult	3,435	20	
		2	3½	....	Ajax Induction	....	..	190,000
Carpenter Steel Co.	Reading, Pa.	4	6	11–0	Swindell-Dressler	4,000	..	
		2	½	....	Northrup Induction	....	..	65,000
Colonial Steel Co.	Colona, Pa.	1	5	10–0	Heroult	2,000	..	8,000
Columbia Steel Co.	Torrance, Cal.	1	3	9–0	Heroult	....	..	7,000
Columbia Tool Steel Co.	Chicago Heights, Ill.	1	6	11–0	Lectromelt	....	..	
		1	3	9–0	Lectromelt	2,500	..	20,000
Connors Steel Co.	Birmingham, Ala.	2	3	9–0	Lectromelt	....	..	12,000
Copperweld Steel Co.	Warren, O.	1	35	17–0	Lectromelt	12,000	18	
		2	35	16–0	Swindell-Dressler	12,000	18	
		1	6	11–0	Lectromelt	5,000	17	
		2	6	11–0	Heroult	2,500 and 5,000	17	230,000
Crucible Steel Co. of America	Harrison, N. J.	3	15	14–8	Heroult	6,000	..	
		3	6	11–0	Heroult	3,000	..	
		1	3	9–0	Heroult	1,500	..	
		1	1	....	Ajax Induction	....	..	
		2	300 lb.	....	Ajax Induction	....	..	146,000
	Pittsburgh, Pa.	2	6	11–0	Heroult	....	..	
		3	1	....	Ajax Induction	....	..	32,000
	Syracuse, N. Y.							
	Halcomb Works	3	6	11–0	Heroult	3,000	..	
		2	3	9–0	Heroult	1,500	..	
	Sanderson Works	2	3	9–0	Heroult	1,500	..	61,000
Driver-Harris Co.	Harrison, N. J.	2	2	7–0	Heroult	....	..	8,000
Firth-Sterling Steel Co.	McKeesport, Pa.	2	3	9–0	Heroult	2,500 and 3,000	..	
		2	1½	....	Ajax Induction	....	..	17,000
Ford Motor Co.	Dearborn, Mich.	7	15	....	Heroult	....	..	
		8	7	11–6	Swindell-Dressler	(6) 2,500; (2) 4,000	..	
		4	5	10–6	Swindell-Dressler	(3) 3,000; (1) 4,000	..	
		2	3	9–0	Lectromelt	....	..	
		9	3	9–0	Swindell-Dressler	(3) 1,000; (3) 1,200; (3) 3,000	..	474,000
Henry Disston & Sons, Inc.	Philadelphia, Pa.	1	6	11–0	Heroult	2,500	..	
		1	3	9–0	Heroult	1,500	..	17,000

OF THE UNITED STATES OF AMERICA

AS OF AUGUST, NINETEEN HUNDRED FORTY-ONE

Company	Location	Number	Nominal size, tons	Approximate shell diameter, ft.-in.	Make of furnace	Transformer capacity, kva.	Diameter of electrodes, in.	Estimated annual capacity, tons
Heppenstall Co.	Pittsburgh, Pa.	2	1,200 lb.	....	Ajax Induction	....	..	2,000
Ingersoll Steel & Disc Co.	New Castle, Ind.	2	3	9–0	Heroult	1,800	..	
		1	5	10–0	Heroult	3,500	..	
		1	1	5–0	Heroult	1,000	..	16,000
Jessop Steel Co.	Washington, Pa.	1	6	11–0	Heroult	4,000	..	
		1	3	9–0	Gronwall-Dixon	2,500	..	17,000
Jones & Laughlin Steel Corp.	Pittsburgh, Pa.	1	1	6–0	Swindell-Dressler	1,000	..	4,500
Joslyn Mfg. & Supply Co.	Fort Wayne, Ind.	1	6	11–0	Lectromelt	6,000	..	13,000
Kilby Steel Co.	Anniston, Ala.	1	3	9–0	Lectromelt	2,500	..	
		1	1	....	Lectromelt	500	..	12,000
Knoxville Iron Co.	Knoxville, Tenn.	2	6	9–0	Lectromelt	3,000	..	19,000
Latrobe Electric Steel Co.	Latrobe, Pa.	2	6	11–0	Heroult	3,000 and 1,500	..	
		1	3	9–0	Heroult	1,000	..	
		1	1	5–7	Lectromelt	500	..	25,000
Lebanon Iron & Steel Co.	Lebanon, Pa.	1	3	9–0	Swindell-Dressler	2,500	..	7,200
Mesta Machine Co.	Pittsburgh, Pa.	1	15	13–6	Swindell-Dressler	5,000	..	33,000
Midvale Steel Co.	Philadelphia, Pa.	1	50	17–0	Swindell-Dressler	10,000	..	
		1	7½	12–0	Swindell-Dressler	5,000	..	
		1	6	11–0	Swindell-Dressler	2,250	..	90,000
National Forge & Ordnance Co.	Irvine, Pa.	1	10	12–0	Heroult	4,000	..	
		1	6	11–0	Heroult	2,500	..	
		1	2	7–0	Heroult	1,500	..	30,000
Northwest Steel Rolling Mills, Inc.	Seattle, Wash.	1	3	9–0	Lectromelt	2,500	..	
		1	6	10–0	Lectromelt	....	..	20,000
Northwestern Steel & Wire Co.	Sterling, Ill.	2	35	17–0	Lectromelt	....	..	100,000
Otis Steel Co.	Cleveland, O.	1	2½	7–0	Lectromelt	....	..	6,000
Pacific States Steel Co.	Oakland, Cal.	3	6	11–0	....	5,000	..	36,000
Pittsburgh Crucible Steel Co.	Midland, Pa.	4	35	15–8; 18–0	Heroult	....	..	216,000
Republic Steel Corp.	Canton, O.	2	70	20–0	Heroult	12,000	20	
		6	60	19–0	Heroult	12,000	18 and 20	
		2	35	16–6	Heroult	10,000	18	
		3	15	14–6	Heroult	4,500	14	
		1	6	11–0	Heroult	2,800	12	
		1	6	....	Induction	....	..	733,000
Rotary Electric Steel Corp.	Detroit, Mich.	2	50	18–0	Heroult	12,000 and 10,000	20	130,000
Rustless Iron & Steel Corp.	Baltimore, Md.	1	25	15–8	Heroult	7,500	17	
		2	15	14–6	Heroult	5,000	17	
		3	12	12–6	Heroult	3,500	17	168,000
Sharon Steel Corp.	Lowellville, O.	1	15	14–6	Heroult	6,000	..	36,000
Simonds Saw & Steel Co.	Lockport, N. Y.	3	6	11–0	Heroult	(2) 2,500; (1) 1,500	..	
		5	..	....	Ajax Induction	....	..	25,000
Texas Steel Co.	Fort Worth, Tex.	1	3	7–0	Lectromelt	2,000	..	
		1	8	10–0	Lectromelt	3,750	..	18,000
Timken Roller Bearing Co.	Canton, O.	1	85	20×29	Heroult	2×7,500	(6) 18	
		1	65	20–0	Heroult	12,000	18	
		1	60	19–0	Heroult	12,000	18	
		2	35	16–6	Heroult	10,000	18	
		1	20	14–8	Heroult	7,500	17	345,000
Union Electric Steel Corp.	Carnegie, Pa.	2	6	11–0	Swindell-Dressler	1,200 and 1,500	..	19,200
Universal Cyclops Steel Corp.	Bridgeville, Pa.	2	12	11–0	Heroult	3,000 and 4,000	17	
		1	6	11–0	Lectromelt	5,000	14	
		1	3	9–0	Heroult	2,000	9	75,000
Vanadium Alloys Steel Co.	Latrobe, Pa.	2	3	9–0	Heroult	2,500 and 1,500	..	
		1	½	....	Ajax Induction	....	..	12,000
Vulcan Crucible Steel Co.	Aliquippa, Pa.	2	3	9–0	Heroult	2,000 and 1,200	..	12,000
Total	....	207	..	....	....	....	..	4,169,100



Figures 1, 2, 3, 4—Sketches showing four schedules of reductions for rolling angles.

ROLLS *and* ROLL DESIGN

By C. Elms

PITTSBURGH ROLLS CORP.

PITTSBURGH, PENNA.

Figure 5—(opposite page) Three methods of rolling small beams: (bottom) angle method (C); center, combination method (B); (top) straight method (A).

▲ ONE HUNDRED AND EIGHTY-SEVEN years ago the first mill was built in England to be used for the rolling of iron. This mill was, as we would view it, a very crude affair. But nevertheless it marked the birth of an industry which today is one of the world's largest.

Today the rolling mill is very elaborate and contains accurate and intricate machinery. Sections as we roll them now are usually measured by a micrometer, therefore, the rolls and mill machinery are machined to the finest detail.

First of all let us view briefly the rolls used in the modern mill. They are usually made of sand iron, carbon steel, grain, chilled iron, alloy iron, alloy steel, forged steel, and quite a large number of modifications of the above, and they are of varying strength and hardness. The finishing stands have the hardest rolls, and are the weakest, and the roughing stands have the softer and stronger rolls; this is natural as the heavier reductions are taken in the earlier stands of the mill, and the lighter reductions in the finishing of the bar, in the final passes.

The turning of rolls is done by a highly skilled mechanic called a roll-turner. He usually serves an apprenticeship on a roll lathe until be becomes a full-fledged craftsman. Many years ago it was the roll-turner, mill superintendent, or the mill roller who designed the rolls for the mill, but the demands upon the mill in the way of new sections made it necessary to place this work in the hands of men specially trained to the work, so that, now roll designing has become a distinct profession.

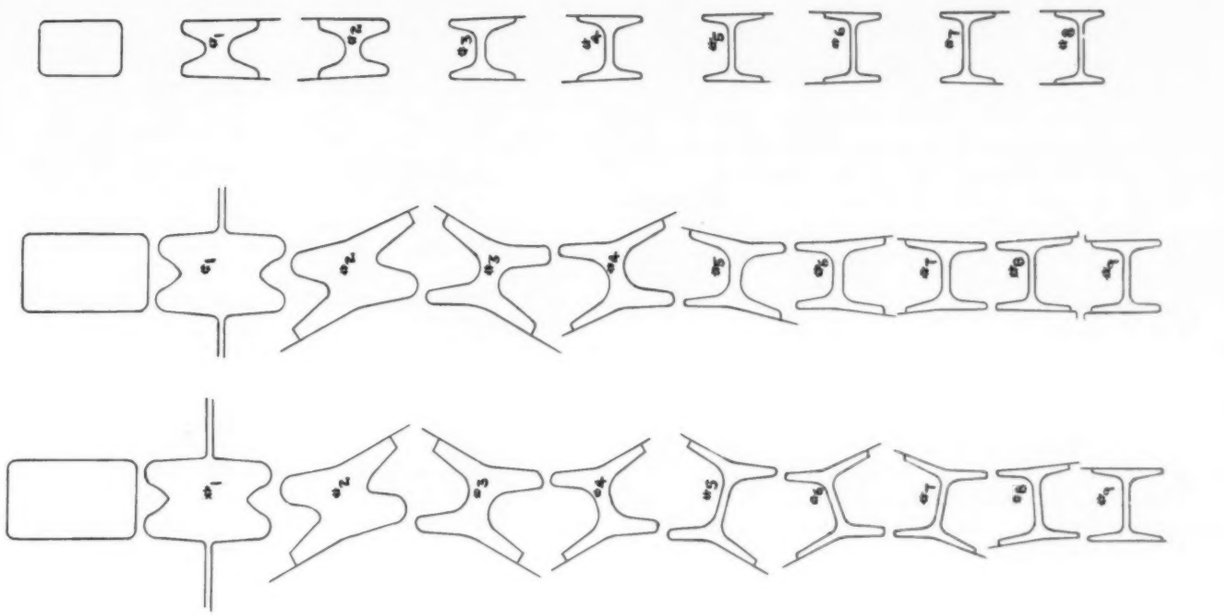
The pioneer roll designer did not have the advantages that we of the present day have; many of them were not educated and they made their simple sections by trial and corrected error. They had little or no knowledge of drawing or mathematics, and usually filed some templets without any preliminary drawing work to turn the passes, and tried each pass separately, or by groups, until they arrived at the proper section. It usually happened that the changes made were not recorded, and only the man who made them knew what they were. The templets were jealously guarded by the designer as his property and were often taken by him if he left the job. Roll drawings were not made and no record kept of designs or rolls.

In late years great advances have been made in the art of designing rolls. Many roll designers now have the proper training; they have a good working knowledge of drawing, mathematics and engineering, and usually have a trained staff of draftsmen and templet filers. By study and through visits to other mills they have increased their knowledge, and have little fear in attempting the most complicated sections. Some of the sections now being rolled were thought impossible some years ago.

The roll designer's work has been made easier by the roll foundries' development of new types and better rolls, which made possible the successful rolling of sections of size and shape which would have been difficult or impossible to roll with inferior rolls.

There are very few text books on roll designing of any practical value, so the roll designer has to get all his knowledge through study and by the school of experience. A thorough knowledge of rolling mill practice of all kinds is necessary, and this can be acquired only by actually doing the work.

The design of rolls for shapes requires a combination of theory, experience and imagination. Through this imagination and experience it is possible to see ahead from the finished shape, the design each pass must take to the ingot it starts from. Knowledge of roll materials and their strength, and wearing qualities is essential. Heating practices and rolling and finishing temperatures must be known. Shrinkage of the steel from the finishing temperature to the cold size, must be also



calculated. The rolling action of the various grades of steel must be given consideration.

The shape of some sections is such that there is considerable difficulty experienced in getting the metal to flow where it is required. The tendency in rolling steel is for the metal to elongate in the forward direction. Thus in beam or channel sections difficulty is experienced in getting the flanges filled up. The natural tendency is for the flanges to go along with the elongation of the web.

It is seldom that two roll designers given the same section will develop the design in exactly the same way; however, it is a matter of two minds working in different ways and both will produce the desired section. It often happens that the designer, in shaping the metal, is confined to the mills at hand, which imposes restrictions as to what he may do. This may force him to design a section which would not be entirely to his liking but is the best he can do considering the mill he has to produce for.

In Figures 1, 2, 3 and 4, four styles of rolling angles are shown. Figure 1 is the oldest style of rolling angles. In this design, raising the rolls to make the heavy section makes the legs very long and the apex of the angle round.

Figure 2 shows the butterfly system. In this scheme, raising the rolls does not make the legs as long as in the Figure 1 setup. Figure 3 shows a method in which the first passes are used for all size of angles, the last three passes being tongue and groove for the particular section being rolled. Figure 4 shows a set-up where the roll passes are the same for all sizes throughout. Vertical rolls control the length of the legs by edging the piece.

You can see from the above that four different designs are sometimes used to make angles, and there are probably a great many more modificatons of the above which will make more or less desirable sections.

The same thing is true on other sections. I will outline three different methods of rolling small beams from a rectangular bloom as shown in Figure 5.

The first method shown is the angle method, meaning the passes are on an angle in the rolls. One live flange is up and the other one is down; the same is true of the dead flanges. This scheme has an advantage in that the live flanges are at an angle with the axis of the roll, which makes possible a heavy draft without "choking" and shortening the flange. A longer and thinner flange can be rolled by this method than would be possible by the straight method (C) due to the spreading angle of the live flanges.

Figure 5 (B) shows a combination of the other two systems pictured, which I call the angle and straight method. This set-up has roughing passes on the angle and the finishing passes straight. The angle system, while having some advantages also has disadvantages, one of which is that only one weight section can satisfactorily be rolled, because where the rolls are raised, the live flange thicknesses are increased, and are then too thick to enter the succeeding dead holes; also the finished beam depth is increased. The angle passes also cause excessive twisting of the bar as they are delivered from the passes. This is natural due to the opposing large and small diameters. The combination angle and straight method overcomes some of these difficulties, in that a reasonable variation in web thickness is possible.

Figure 5 (A) shows the straight method of rolling beams. In the straight method if a heavy draft is put on the sides of the live flanges it will cause the flange to elongate with the web and therefore the flange will not fill up. In cases where three high rolls are used and passes must work over each other, it is almost impossible to have a good distribution of draft. It must be said that greater variation in foot weights can be obtained

by the straight method than either of the other two systems.

You can readily see from the above sections some of the problems with which the roll designer has to contend; he has a multitude of things that must be kept in mind, some of which are:

The proper position of the pitch line.
Method of shaping, bending, squeezing and spreading.
Working the different sides of the piece.
Total amount of reduction and how to distribute same.
Roll diameter with relation to deep cuts to avoid weakening the rolls.
Reductions from one pass to the next.
Avoidance of fins or extreme underfilling.
Proper proportioning of drafts.
Properties of the section with regard for cooling of thin parts.
Working diameters of the piece.
Provision for proper guiding of the section.

The proper location of the pitch line is an item of roll designing that has been a subject of much discussion and has a large part in governing and controlling the successful rolling of a section. This has led to so called "thumb" rules. One of the most commonly used rules is to place the pitch line so that it passes through the center of gravity of the area of the section. We are also accustomed to the use of balancing a cardboard templet of the section on a knife edge or triangular scale to determine a balance between the upper and lower halves of the section. Some designers with more than usual

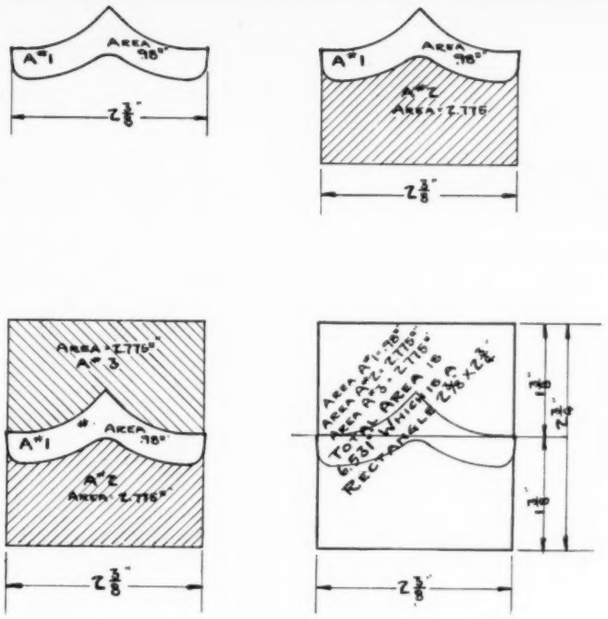
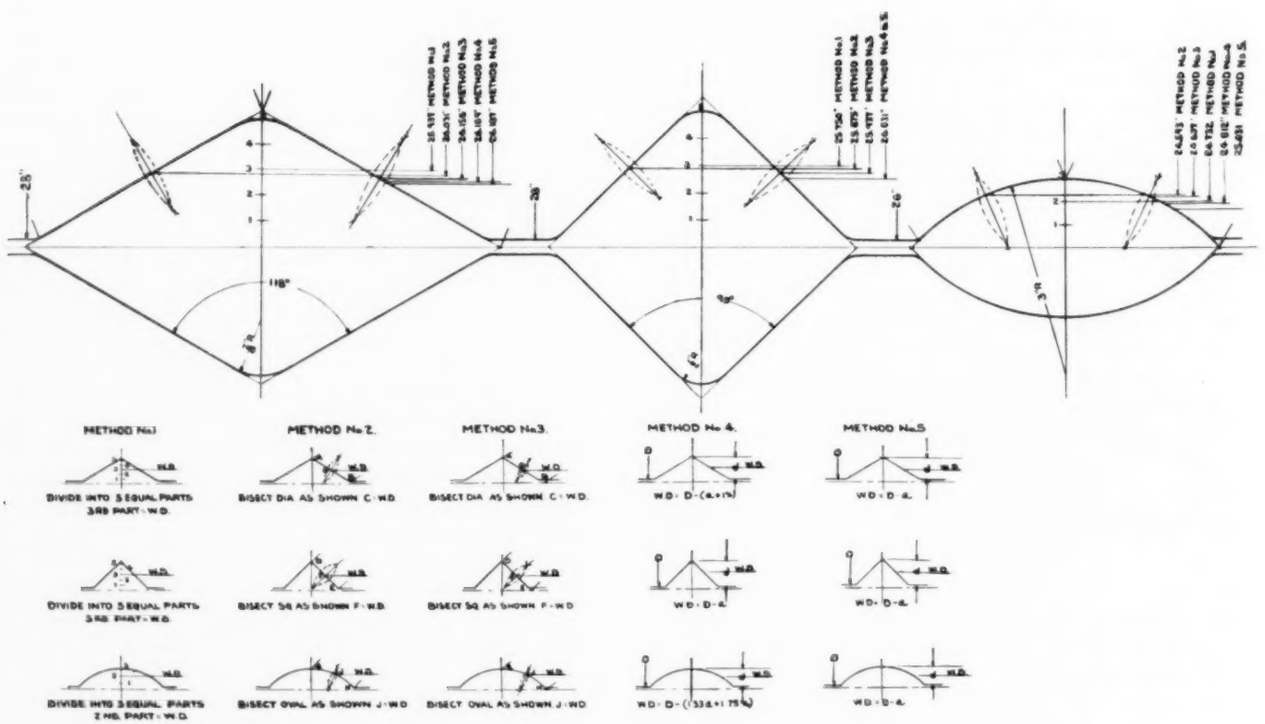


Figure 6—Sketch illustrating Lennox method of finding pitch diameter for sectional shapes.

●

Figure 7—Working diameters of passes for sectional shapes are figured by various methods, five of which are indicated here.


METHOD No.1
METHOD No.2
METHOD No.3
METHOD No.4
METHOD No.5
DIVIDE INTO 3 EQUAL PARTS
3RD PART = W.D.
BISECT DIA AS SHOWN C = W.D.
BISECT SQ AS SHOWN F = W.D.
BISECT OVAL AS SHOWN J = W.D.
2 ND. PART = W.D.

judgment can place a pitch diameter on a section fairly close without balancing or figuring; this comes only after years of experience and is usually a fairly good guess.

We roll designers are accustomed to having a new formula for doing some particular job brought to our attention, and nine times out of ten these rules are valueless. However, one of our prominent roll designers has developed and proven in his plant, far beyond the experimental stage, a method of finding the pitch-diameter on any kind of a section, symmetrical or non-symmetrical, regardless of shape. This new system of finding the pitch-diameter was developed and is in use every day by David Lennox, roll designer of Atlantic Steel Company, Atlanta, Georgia. In Figure 6 is illustrated Mr. Lennox's method. A-1 represents the section on which we desire to find the pitch line. The area of this section we must know, and we usually do, as same is taken when section is laid out.

Next we construct an addition to the section in the form of a rectangle, as shown with A-1 and A-2 together. It is necessary to take the area of part A-2 exclusive of A-1. Do not at this time add these two areas together. A-2 can extend any distance below the actual section.

The third step is to construct another rectangular section above A-1 as shown in the drawing with A-1, A-2 and A-3 together. This third section A-3 must equal in area A-2. We now have three separate parts, the areas of which are added together. These three parts form a rectangle, the area of which is known. The width of the rectangle is the same as the pass at its widest point. So it is a simple matter to convert the area into a dimensional rectangle. We know that the width times the length equal the area of a rectangle. So with the area and the width known, we have only to divide the area by the width to give us the length. After we have the length we divide same by two, which places a line half way on the rectangle which locates the exact center line of the rectangle and at the same time places the pitch line on our section as is shown on the last picture of this illustration. So we can say, that if the correct position of the pitch line is the place where it passes through the center of gravity of the area of a section, Mr. Lennox has given us a simple method and an accurate formula for finding this position.

On continuous type mills it is necessary to establish a controlling or working diameter of the passes; this means a corresponding pass speed in both rolls at which the bar is being delivered. This working diameter, also called rolling or controlling, is used in figuring a constant, or coefficient in continuous rolling.

There are quite a number of methods of figuring this working diameter, five of which are shown in Figure 7 with a complete working explanation of each one. These are all being used in various mills throughout the country and each one is adaptable to any continuous mill. You will notice that they are grouped on three different types of passes, and the working diameters are fairly close together, so it would seem that it is a matter of choice which one is used.

Mr. Lennox, in conjunction with his method of finding the pitch diameter, went a step farther and has found a unique and simple way of finding the working diameter. We will explain in detail his method using the same

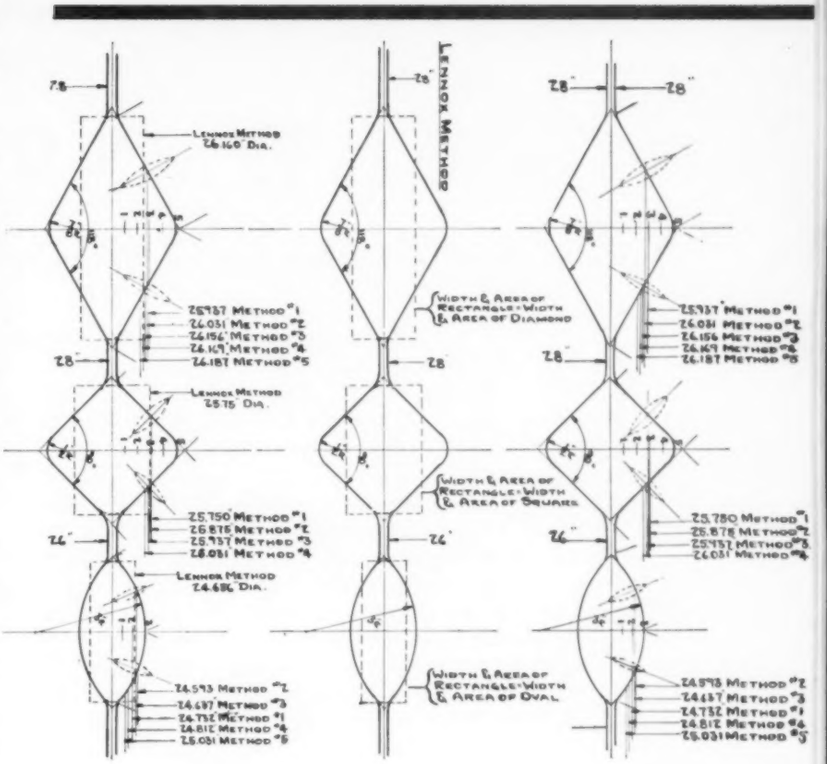

LENNOX METHOD
LENNOX METHOD
WIDTH & AREA OF RECTANGLE: WIDTH & AREA OF DIAMOND
WIDTH & AREA OF RECTANGLE: WIDTH & AREA OF SQUARE
WIDTH & AREA OF RECTANGLE: WIDTH & AREA OF OVAL

Figure 8—Sketch showing application of Lennox method in finding working diameter of passes.

sections as outlined in Figure 7, *i.e.*, the diamond, square and oval.

The Lennox method, as we call it, is to take the area of the pass, and construct this area into the shape of a simple rectangle, using the extreme width of the pass for the one dimension and dividing the area by this width. For example: area of the pass (6 sq. in.) divided by 3 in. extreme width equals 2 in., height of rectangle.

This rectangle is constructed about the pitch line, half above and half below the pitch. The examples in Figure 8 better illustrate the simple method of applying this method to a pass.

We offer Mr. Lennox's methods not as a criticism of practices now in use for finding pitch and working diameters, but because these two systems are new to most of us, and will probably be a help to quite a few designers and draftsmen who are always looking for some different method.

We might add that Mr. Lennox has sections on his mill in daily operation, worked out by the above principles and we wish to thank him for his kind permission to present these ideas.

You can readily see from the points brought out in this paper that a roll designer has been an important factor in the progress of the steel industry and should be congratulated on the various types of difficult sections being produced today. His importance in this industry should not be under-estimated as he sometimes is called upon to do things in roll design that would often times seem to be impossible.

The SAWING of METALS

By C. M. Thompson, HENRY DISSTON & SONS, INC., PHILADELPHIA, PENNA.

Presented before A. I. S. E. PHILADELPHIA SECTION, November 2, 1940

▲ METALS may be cut by any one of three methods; with band saws, hack saws and circular saws. Each has its own field of application and its advantages and limitations.

The band saw is manufactured in two types. The "hardened throughout" band, which is sometimes referred to as spring tempered, is used for cutting sheet steel at high speeds, 10,000 to 12,000 ft. per min., which is in reality friction cutting. The limit of the sheet steel stock is about 1/16 in. It is also used in some cases for sawing non-ferrous metals, particularly aluminum. It can be resharpened and reset as it wears down. The other type, known as hard edge-flexible back band is hardened on the tooth edge only and cannot be resharpened. This type is by far the most universally used. Its principal application is in the field of sawing irregular shapes such as dies, jigs, templates and patterns. It is also quite generally used for cutting off the gates and risers from small castings, particularly of non-ferrous metals. This type is operated at speeds ranging from 90 to 3000 ft. per min.

Table I gives the recommended number of teeth per inch and speed for hard edge-flexible back band saws for cutting various materials.

To obtain maximum efficiency in the operation of

Figure 1—Chart showing classification of circular saws for metal cutting.

	TOOTH SPACING				HOOK AND RAKE ANGLES				SPEED			
MILLING SAWS	Steel	Brass	Copper	Aluminum	Steel	Brass	Copper	Aluminum	S	B	C	A
Screw Slotters	1/8	1/8			0	0			60			
Metal Slitting	1/2	1/2			0	0			40			
Milling	1/4 - 1	1/2 - 1	3/8 - 1		0	0	10-15		40			
Inserted Tooth	1 - 5	1 - 1 5/8	1 - 1 5/8	1 - 1 5/8	8 - 12	12-15	12-17	15-20	40	800	500	1200
Metal Saws	1/8 - 1/2	1/8 - 1/2	1/4 - 1/2	3/8 - 5/8	0	10-15	10-15	15-20		4000	4000	8000
Tube "	1/8 - 5/8				0				18000			
Hot "	3/4				Neg.				22000			
Friction " (Cold)	5/32				0				25000			

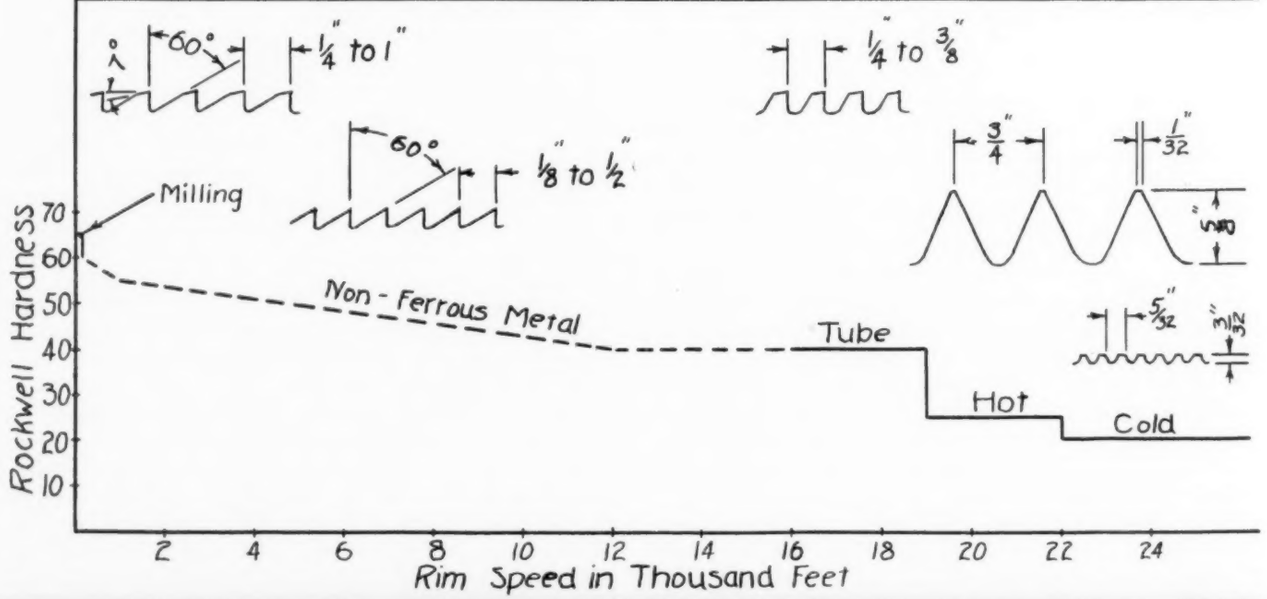


TABLE I

Recommended Specifications for Hard Edge Flexible Back Band Saws

Material	Number of teeth per in.	Speed in ft. per min.
Aluminum	8–10	800–2500
Brass castings—Soft	10–14	700–1500
Hard	10–14	200– 500
Brass tubing	14–18	700–1500
Bronze	10–14	150– 350
Cast iron	12–14	100– 125
Copper	8–12	500–1000
Copper-nickel	12–14	70– 90
Inconel	10–12	70– 90
Iron bars	12–14	100– 125
Iron sheets (under $\frac{1}{32}$ in.)	14–18	100– 250
Monel metal	10–12	100– 150
Nickel silver	18–24	100– 150
Pipe—iron	14–18	100– 200
Steel—Chrome	12–14	90– 125
Cold rolled	10–12	100– 125
Drill rod	14	100– 125
High speed	12–14	90– 125
Machinery	10–14	100– 125
Manganese	10–12	90– 100
Nickel	10–14	90– 125
Structural	10–14	90– 125
Tool	12–14	100– 125
Tubing	14–18	100– 150

metal cutting band saws, attention should be paid to:

1. Teeth should project over the edge of the wheels.
2. Band should be adjusted in guides so that teeth project.
3. Guides should preferably be of the roller type.
4. Guides should be kept in alignment.
5. Proper tension should be maintained at all times. Approximately 300 lb. per inch of width.
6. Operate at recommended speeds.
7. Keep guides as close to work as possible.

Since the primary interest is in production cutting, the hand hack saw blade will not be considered here. Power hack saw blades may be classed as one type, although they are manufactured from high-speed steel, molybdenum and carbon alloy.

The selection of the proper blade and correct operating speed will produce maximum results. As a guide, Table II is offered.

High speed steel blades should be used for cutting stainless steel, high speed steel, chrome-nickel and similar alloys, where machine conditions are good and blades are not subject to abuse.

Molybdenum blades may be used for cutting tool steels, machinery steels, cast iron, structural shapes, tubing and thin wall sections and where blades are subjected to abuse such as cluster cutting.

The carbon alloy hack saw blade is satisfactory where the cutting is occasional and does not warrant the use of a more expensive blade.

The common abuses of power hack saw blades are:

1. Failure to keep blade perpendicular to work and flush with machine frame.
2. Careless starting. Allowing blade to drop on work.
3. Over-feeding to the extent of stripping teeth.
4. Under-feeding to the extent of dulling blade by abrasion.
5. Over-speeding.
6. Failure to strain blade tightly.
7. Failure of machine to lift blade on back stroke.
8. Failure to increase pressure as blade dulls.
9. Failure of flow of coolant.
10. Improper application.

The circular saw for metal cutting covers the broadest field and the ramifications are many. This type is best classified as shown in Figure 1. The forms of teeth shown are typical although there are variations in the milling saw group. Particular attention is drawn to the fact that ferrous materials can only be successfully cut at the extreme ends, namely 40 to 60 ft. per min. rim speed and at 16,000 to 25,000 ft. per min. The range of speeds between these two limits is applicable only to the sawing of non-ferrous metals.

One of the problems frequently confronting the production departments in steel mills and allied industries is the selection of the most economical type for sawing steel. It is of interest, therefore, to examine the cost figures shown in Table III. These are actual figures obtained from production cutting of the same material with a power hack saw machine and a circular cut-off machine. It will be noted that the time per 1000 cuts

TABLE II

Recommended Specifications for Power Hack Saws

Material	Number of teeth per in.	Strokes per min.
Aluminum	4– 6	135
Babbitt	4– 6	135
Brass castings—soft	4– 6	135
Brass castings—hard	6–10	135
Bronze castings	4– 6–10	90
Cast iron	6–10	90–135
Copper tubing	10	90
Copper bars	4– 6	90
Carbon tool steel	6–10	90–135
Die blocks	4– 6	60– 90
Drill rod	10	90–135
Forging stock—mild	4– 6	90–135
Forging stock—alloy	4– 6	90
Machinery steel	4– 6–10	90–135
Malleable iron	6–10	90
Monel metal	6–10	60– 90
Nickel alloy	6–10	60– 90
Pipe, iron	10–14	135
Rails	6–10	60– 90
Stainless steel	6–10	60– 90
Structural steel	10	90–135
Tubing—steel	14	135

TABLE III

Comparative Sawing Costs

Material: 1¼ in. round SAE-6150, Brinell hardness 300.
Hack saw vs. inserted tooth circular saw.

	Hack saws		*Circular saw*	
Size of saw blade	14″ x 1¼″ x .065″ ,6 T.		32″ x ¼″, 66 T.	
Speed of saw	100 strokes per min.		45 ft. per min.	
Feed in sq. in. per min.	0.82		2.27	
Total number of cuts	1380		4186	
Number of saws used	11		1	
Number of sharpenings	..		10	
Cost per blade		$ 0.756		$ 195.00
Cost of sharpening		....		21.05
Teeth replaced		....		10.50
Total saw cost	($0.756×11)	$ 8.32		$ 226.55
Approximate machine cost		$600.00		$2000.00
Time per 1000 cuts	25 hours		9 hours	
Saw cost per 1000 cuts		$ 6.03		$ 54.12
Machine cost per 1000 cuts		1.13		1.35
Labor cost per 1000 cuts		16.25		5.85
Total cost per 1000 cuts		$ 23.41		$ 61.32
On equal production basis:				
Time per 1000 cuts	8.33 hours		9 hours	
Saw cost per 1000 cuts		$ 18.09		$ 54.12
Machine cost per 1000 cuts		1.12		1.35
Labor cost per 1000 cuts		5.41		5.85
Total cost per 1000 cuts		$ 24.62		$ 61.32

is in the approximate ratio of 3 to 1 in favor of the circular saw and to obtain the same production per hour would require three hack saw machines. The cost of cutting, on an equal production basis, is shown at the bottom of the table, and indicates an advantage in the hack saw over the circular cut-off saw. While these figures are taken from actual experience, they are offered merely as a guide and are not to be considered as representative of all applications.

The tube saw, as the name implies, is designed for sawing tubing. It may also be used for sawing other thin wall sections, such as mouldings and similar shapes. It should be kept in mind that the tube saw is designed and offered for ferrous metal cutting only. Tubes and mouldings of non-ferrous metals are an application for metal saws operating in the speed range from 500 to 15,000 ft. per min.

The circular saws of most interest to the steel industry are the hot and cold or friction disc. These range in diameter from 40 to 72 in. and in thicknesses of ¼ to ½ in. respectively.

Figure 2 shows the approximate size of billets recommended for different diameter blades as well as the comparison of speed of cut for both hot and cold sawing.

On the lower right of the chart is a curve showing the approximate horsepower required for different diameter of blades.

The curve at the upper right shows actual horsepower readings taken from a 150 hp. motor driving a 48 in. diameter by ¼ in. thick hot saw when cutting a 5½ in. round in 3½ seconds.

The curves shown on this chart are average and variations are to be expected depending upon the type of drive and other machine conditions as well as the grade of material.

The principle upon which hot and cold saws are operated is based upon getting the blade through the cut in the least possible time and maintaining the maximum differential in temperature between the blade and the work.

The two factors which tend to decrease the efficient operation of hot and cold saws to the greatest extent are lack of sufficient power and improper water coolant supply. Motors and drive should be so selected that there is not more than a 10 per cent decrease in speed of the saw blade for maximum size of material to be cut.

The water supply for light cutting should be from 90 to 150 lb. per sq. in. pressure and for heavy cutting from 300 to 500 lb. per sq. in.

Even if the water pressure is sufficient, it must be applied in the proper manner or it will not be effective. Figure 3 shows the correct method, as well as an

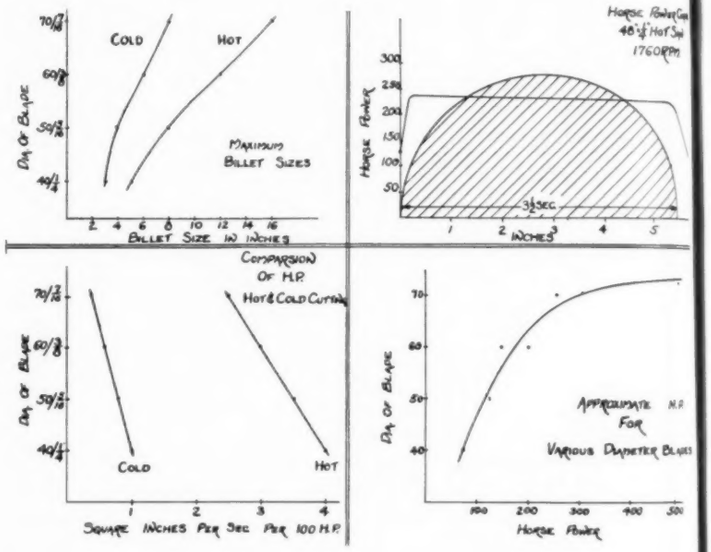
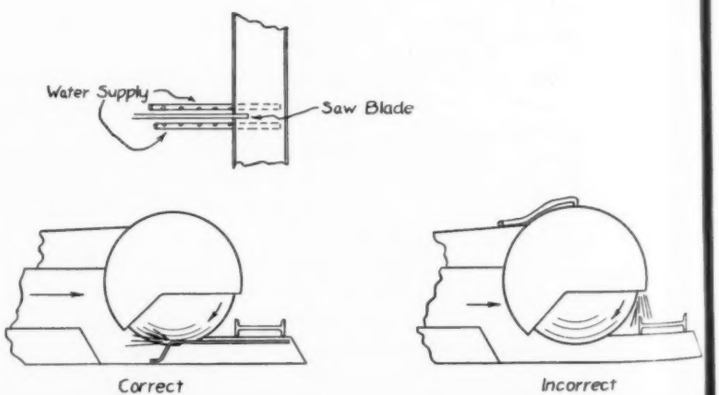


Figure 2—Chart giving various data for hot and cold sawing of steel billets.

Figure 3—Correct application of saw coolant is essential for efficient performance of hot and cold saws.



incorrect method, of applying the coolant water. You will note that in the correct method, water is supplied through two pipes parallel to the saw blade and below or underneath the work. This gives maximum cooling to the blade as it leaves the cut and at the same time reduces the excess from flowing around and over on to the material being cut. The example of the incorrect method of applying cooling water, on the other hand, results in a large percentage actually reaching the work and cooling it rather than the blade, thereby decreasing the temperature differential.

The recommendations and precautions presented herein should result in better saw blade performance and consequently higher efficiency and better economy in the sawing of metals.

DISCUSSION

PRESENTED BY

J. F. BLACK, *General Foreman,* Continuous Butt Weld Mill, Bethlehem Steel Company, Sparrows Point, Maryland

R. W TILFORD, *General Foreman,* Rail Finishing Department, Bethlehem Steel Company, Sparrows Point, Maryland

L. F. COFFIN, *Superintendent,* Mechanical Department, Bethlehem Steel Company, Sparrows Point, Maryland

C. M. THOMPSON, Sales Engineering Department, Henry Disston and Sons, Inc., Philadelphia, Pennsylvania

LOUIS MOSES, *Superintendent,* Rail Mill and Roll Department, Bethlehem Steel Company, Sparrows Point, Maryland

J. F. BLACK: If Mr. Thompson is right, we have a wrong application of cooling water to our saws for cutting hot pipe. I don't know how much difference there is in cutting pipe and solid steel, but we cool our saw by applying the water higher up on the blade than Mr. Thompson recommends.

Due to the fact that our saws are not lasting very well there is a question as to whether we are cooling them properly. I think we could do some studying on this subject and possibly improve our saw life by following some of the advice contained in this paper.

R. W. TILFORD: With a special job of hot sawing performed some years ago it was found that the additional time of sawing with a necessarily retarded feed allowed too much cooling water to be thrown from the blade onto the work. This volume of water chilled the material being cut in that path through which the cut was to be made and created not only a problem to the cutting itself but also adversely affected the quality of the material being cut. To correct this condition a set of vanes was placed within the saw guard and so arranged as to deflect most of the water so it would not impinge upon the hot metal being sawed.

The benefits of not cooling the zone through which the cut is made are obvious and with the application proving so satisfactory on the special job it was also applied to the standard hot saw with equal success.

Cold sawing presents an entirely different set of conditions, especially with compound sections such as rails and beams. While we do not cut structural shapes the higher carbons of rails with their massive head areas and thin webs and flanges present equal difficulties. The pressures applied to cut through a massive head are suddenly released and the saw teeth dig into the thinner members. In other words the saw works in a series of jumps. Inserted tooth construction demands a tooth pitch which is coarser than the dimensions of the web and flange of the section being cut.

It was initially recognized at the time of installing some new cold saw machines that the teeth must be perfectly true on the blade periphery and that hand grinding was taboo. Accordingly all tooth sharpening is done on a machine purchased for the purpose so that each tooth has the same height as its neighbor. In the event of a replacement of one or a few teeth the new ones are ground down to the remaining portion of the assembly after which all are reground at one setting.

On rails up to and including 90 lb. per yd. no particular difficulty is found but the latter multiplies all out of proportion when 131 lb. rails of .75 carbon and .85 manganese are cold sawed. This tough and high tensile material creates a problem in saw tooth quality alone to say nothing about the foregoing described conditions. In all of this it must be understood that the workmanship of the finished cut on a new rail is specified to be within a tolerance of $\frac{1}{32}$ in. of being square and without belly or bowing.

It is not always possible to employ semi-skilled labor on such operations. This places a premium on the machine's ability to withstand abuse. However, it is found that the saw blade is most often the limiting factor on the amount of work which can be performed. We have found that hydraulic feeds are superior to mechanically arranged feeds because a back pressure can be applied which prevents the above described digging in of the teeth when released from the heavy heads and entering the thin web.

L. F. COFFIN: I presume that windage is the principal cause for requiring high pressure water to be used in cooling saws traveling at speeds up to 29,000 ft. per min. In this connection it might be well to point out that some rolling mill superintendents insist on high pressure water for roll cooling even though no more water be used at a higher pressure. In many cases, this is logical and undoubtedly bears some relation to saw cooling.

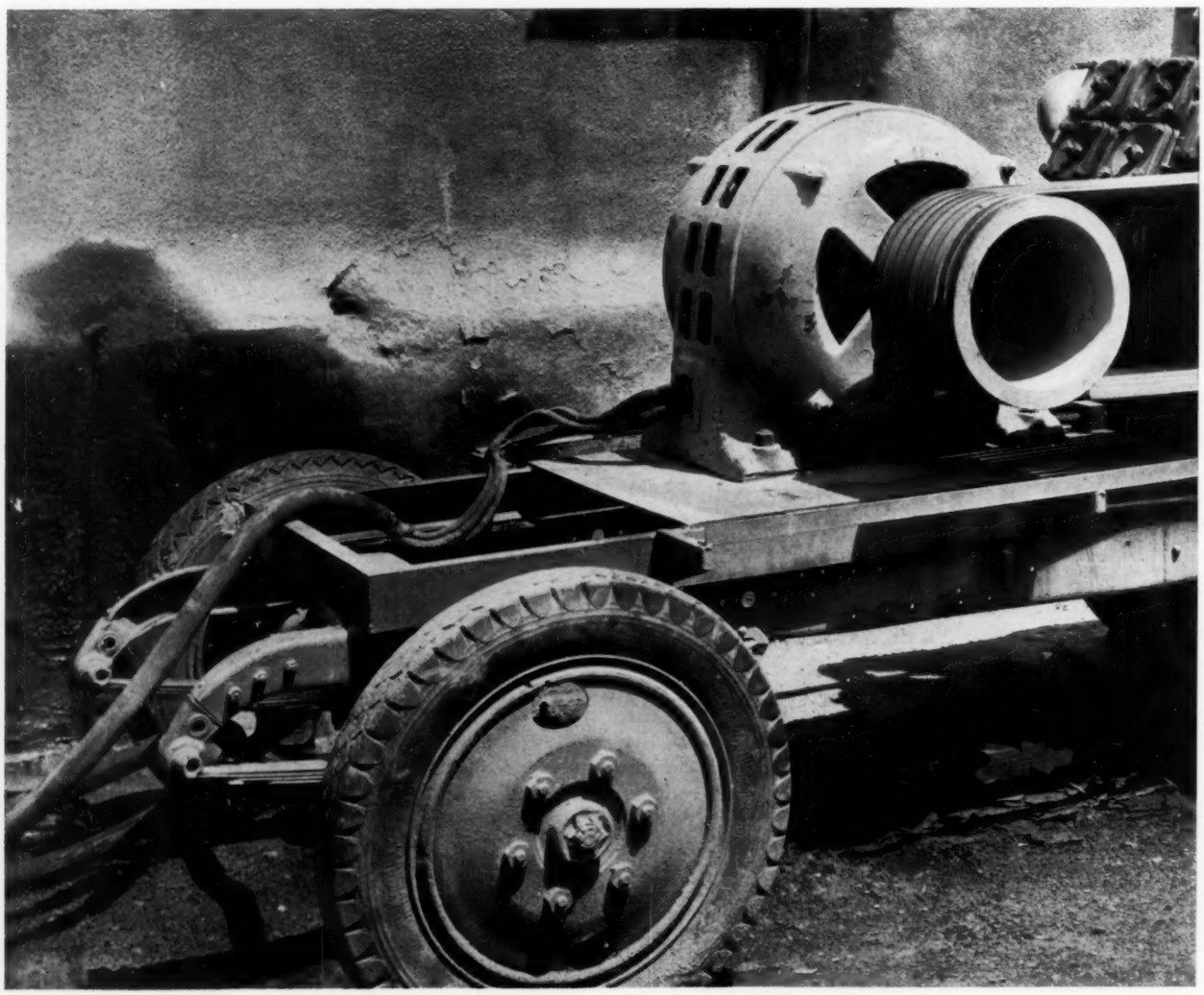
C. M. THOMPSON: I didn't mean to create the impression that the water pressure had to be increased, in the operation of hot saws as you expressed it—the idea is simply to get the water on the blade; with the high peripheral speed the water, unless at sufficient pressure, won't reach the blade. After it reaches the blade of course it will have a tendency to adhere to the blade, keeping it cool. For heavy cutting, the water pressure should be higher because of the fact that the blade is relatively larger. You are in the cut longer than on lighter work and you want to keep the water on that blade just as much as you possibly can. In other words,

(*Please turn to page 78.*)

..."ON COLD MORNINGS OUR COMPRESSORS OFTEN BLEW FUSES...

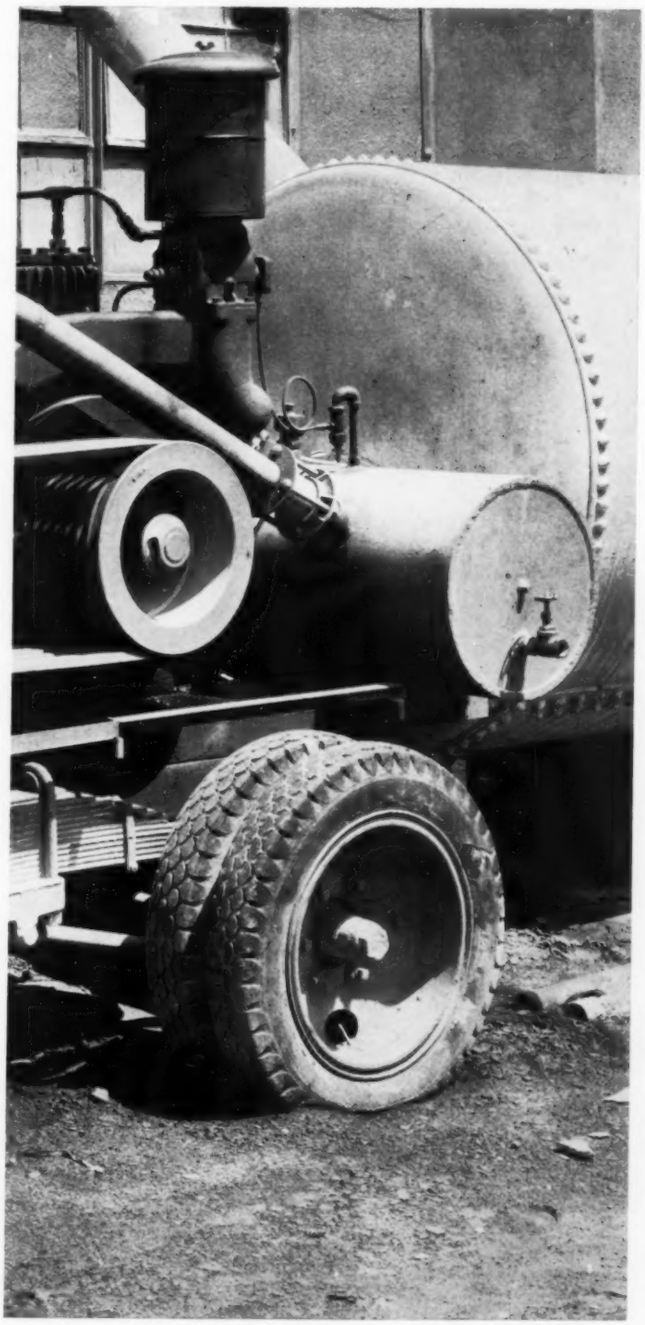
Then we installed *BUSS Super-Lag FUSES* and cured the trouble"

O. S. GREGORY, Electrician
DEWEY PORTLAND CEMENT CO., DAVENPORT, IOWA



"We use three portable compressors, powered by 3 phase 60 cycle 440 volt motors," continues Mr. Gregory. "These compressors stand outdoors all the time. On cold mornings after they have not been used all night the oil in them is very stiff. This causes a heavy starting load and the resulting current surge often blew fuses—which interfered badly with getting work under way.

"About 1936 we installed BUSS Super-Lag fuses. We find they hold where other fuses failed. They proved a practical cure for shutdown troubles.



If Useless Shutdowns Cause Work Stoppage in Your Plant—Maybe Buss Fuses Can Help You Too

In the case cited by Electrician Gregory it is the time-lag built into the BUSS Fuse-Link that permitted compressors to start under the same conditions that had formerly caused ordinary fuses to blow.

The "lag-plates" attached to the BUSS Fuse-Link are responsible for this desirable time-lag. Unusually heavy starting currents or other harmless overloads seldom cause BUSS Super-Lag fuses to open—yet with all this time-lag they will operate under heavy overload or short-circuit conditions as safely as any fuses made.

Fuse-Case Design Also Helps Prevent Shutdowns

It takes more than time-lag to prevent needless blows. Poor contact must be prevented, otherwise excess heating will soon raise the temperature of the link and cause it to blow needlessly. Then the circuit is out and the user is penalized by a useless shutdown.

The BUSS Fuse-Case is designed to insure good contact on the link, even when renewed by an inexperienced person—and is so designed that vibration or heavy overloads or constant heating or cooling of the fuse will not permit poor contact to develop.

Given good contact in the clips BUSS fuses will always carry their rated load and will not open needlessly no matter how long they are in service.

Act on the Facts

If you are interested in preventing many "false-alarm" blows that are entirely unnecessary—

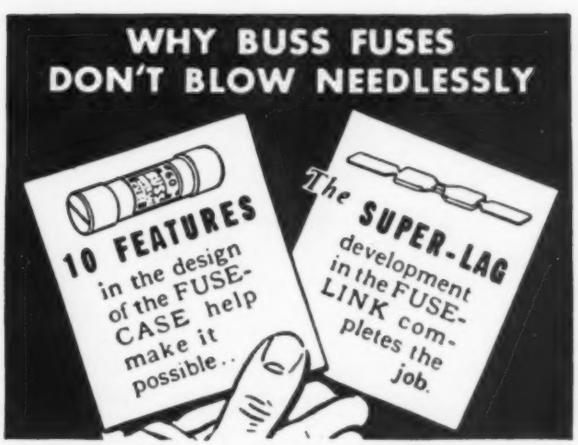
If you want to keep things humming and save needless waste of maintenance time—

If you believe that a protective device should protect against senseless interruptions of electrical service as well as against electrical hazards—

You will find it to your advantage to act at once and standardize on BUSS Super-Lag Renewable Fuses.

Bussmann Mfg. Co., University at Jefferson, St. Louis—Division McGraw Electric Company

BUSS Super-Lag FUSES


WHY BUSS FUSES
DON'T BLOW NEEDLESSLY
10 FEATURES
in the design of the FUSE-CASE help make it possible..
The SUPER-LAG
development in the FUSE-LINK completes the job.

ADVERTISING PAGES REMOVED

THOMPSON DISCUSSION...

(*Continued from page 75*)

if we could flush the blade, we would be even better off The only reason for the increase in water pressure is to maintain the water on the blade in the heavy cut, or as it leaves the cut. Of course, the blade will tend to heat up more rapidly in the heavy cut than in the light.

LOUIS MOSES: I would like to add to Mr. Tilford's remarks that we also believe considerable benefit is derived by the use of pressure water through its blowing off any adhering chips. Such chips, chilled as they are, add greatly to the load on tooth points when the latter come around and re-enter the cut. Our practice conforms to Mr. Thompson's recommendations that cooling water be applied to the blade after it leaves the cut.

C. M. THOMPSON: Yes, it tends to blow the chip off. That is true. We had a case a week or so ago in our own mill which shows that up clearly. The blade slipped on the arbor, not to the extent that it stopped in the cut—it was rotating, but it was slowed up, and there was a section of 8 or 10 in. in length on the periphery loaded up with chips, and you will get that condition where you have a falling off in speed, which was one of the things I pointed out. You must maintain that speed. If it drops off, you are going to pick up more metal, and the higher the water pressure, the more the tendency to blow off the chips. That is another advantage in applying the water under the work rather than on top. If you pick up chips you are putting on much more load on the tooth and it possibly results in a ruined blade.

A. I. S. E. District Section Activities . . . . .

PITTSBURGH, NOVEMBER 5, 1941, WILLIAM PENN HOTEL

Symposium—Methods for Increasing Production from Existing Equipment

Coke Plants—W. T. Brown, Research Engineer, Jones and Laughlin Steel Corporation, Pittsburgh, Pennsylvania

Blast Furnaces—L. E. Riddle, Superintendent of Blast Furnaces, Carnegie-Illinois Steel Corporation, Duquesne, Pennsylvania

Open Hearth—F. C. Swartz, Superintendent of Open Hearths, Carnegie-Illinois Steel Corporation, Youngstown, Ohio

Bessemer and Duplexing—L. P. Lias, Plant Metallurgist, Jones and Laughlin Steel Corporation, Pittsburgh, Pennsylvania

Mill Equipment—Joseph Malborn, Engineer, United Engineering and Foundry Company, Pittsburgh, Pennsylvania

PHILADELPHIA, NOVEMBER 1, 1941, ENGINEERS CLUB

Symposium—Increased Production from Existing Facilities

Open Hearth—R. L. Willis, Superintendent of Combustion, Bethlehem Steel Company, Bethlehem, Pennsylvania

Electric Arc Furnaces—G. O. Van Artsdalen, Superintendent of Maintenance, Henry Disston and Sons, Inc., Philadelphia, Pennsylvania

Plate Mills—A. F. Franz, Superintendent, Steel Division, Alan Wood Steel Company, Conshohocken, Pennsylvania

DETROIT, NOVEMBER 11, STOCKHOLM RESTAURANT

"Recovery of Benzol Products by the Continuous Process," by C. R. Lohrey, Superintendent, By-Products Department, Great Lakes Steel Corporation, Ecorse, Michigan

BIRMINGHAM, NOVEMBER 24, THOMAS JEFFERSON HOTEL

"Recent Developments and Improvements in Power Plant Design and Operation," by J. M. Galallee, Dean of Engineering, University of Alabama, Tuscaloosa, Alabama

CHICAGO, NOVEMBER 11, PHIL SMIDT'S RESTAURANT

"Improvements in Blast Furnace Filling Equipment," by Arthur J. Whitcomb, Freyn Engineering Company, Chicago, Illinois

For every service in the Iron and Steel Industry there is a JOHNS-MANVILLE INSULATION specially designed to provide highest operating efficiency, long life and maximum fuel savings - - -

Listed below are brief facts on a few of the most widely used J-M Insulations. For full details, and for information on the free J-M Insulation Engineering Service, write Johns-Manville, 22 East 40th Street, New York, N. Y.

• • •

SUPEREX BLOCKS—The most widely used block insulation for temperatures to 1900° F. Combines high heat resistance with low thermal conductivity. Furnished 3" to 12" wide, 18" and 36" long, from 1" to 4" thick.

J-M INSULATING BRICK AND INSULATING FIRE BRICK—The new complete J-M line offers three types of insulating brick, four types of insulating fire brick. The insulating brick—Sil-O-Cel Natural Brick (for temperatures to 1600° F.), Sil-O-Cel C-22 Brick (for temperatures to 2000° F.), Sil-O-Cel Super Insulating Brick (for temperatures to 2500° F.). The insulating fire brick—JM-16 (for temperatures to 1600° F.), JM-20 (for temperatures to 2000° F.), JM-23 (for temperatures to 2300° F.), JM-26 (for temperatures to 2600° F.). All seven brick provide unusually light weight, low conductivity, ample strength and low cost. Furnished accurately sized in all standard 9" shapes of the 2½" to 3" series, as well as in special sizes.

SIL-O-CEL C-3 CONCRETE—Cast on the job from Sil-O-Cel C-3 aggregate and cement. Sets up into a strong, durable semi-refractory insulating concrete for temperatures up to 1800° F. Crushing strength: 1000 lbs. sq. in.

J-M 85% MAGNESIA BLOCKS AND PIPE INSULATION—Long recognized as the standard material for temperatures to 600° F. Maintains its high insulating efficiency through years of service. Often used in combination with Superex Blocks and Pipe Insulation at temperatures over 600° F. Blocks 3" to 12" wide, 18" or 36" long, 1" to 4" thick. Pipe Insulation in all standard sizes.

ASBESTO-SPONGE FELTED PIPE INSULATION—The most efficient and durable material for temperatures up to 700° F. Also used in combination with Superex Pipe Covering for higher temperatures. Specially suited to the severe conditions encountered in steel-mill service. Furnished in all standard sizes.

ADVERTISING PAGES REMOVED

P. J. BOWRON

E. W. TREXLER

E. J. WAGAR

A. I. S. E. District Section Chairmen

P. J. Bowron was graduated from Carnegie Institute of Technology in 1926 with the degree of B.S. in chemical engineering. He then entered the employ of Koppers Construction Company, resigning after two years to take a position with Tennessee Coal, Iron and Railroad Company at Fairfield Steel Works, in the steam engineering department. He then spent two years in the fuel engineering department, five years in the metallurgical department, and two years as general practice man at Fairfield Steel Works, being placed in his present position as assistant superintendent of annealing when Fairfield tin mill was under construction in 1937.

E. W. Trexler was born in Allentown, Pennsylvania, and was graduated from Lehigh University in 1912 in mechanical engineering. From 1912 till 1917 he was employed by the Ingersoll-Rand Company at Painted Post, New York. He has been at Cambria Plant, Bethlehem Steel Company, since 1917, serving in various capacities until appointed to his present position of superintendent of the mechanical department.

E. J. Wagar was born in Cleveland, Ohio, and after graduating from high school in 1922, continued his education by taking a correspondence course in mechanical engineering, later enrolling in and receiving his bachelor's degree in engineering from the evening division of Fenn College. Following high school, Mr. Wagar began work as an apprentice tool maker. He entered the employ of the Otis Steel Company in 1925 as a machinist at its Lakeside Works, and subsequently served as assistant to master mechanic, power house foreman, assistant steam engineer, and mechanical engineer. In 1937 he was promoted to his present position as assistant chief engineer.

H. R. Zimmerman started work for the United States Steel Corporation in 1911 at the Gary Sheet Mill Plant of the American Sheet and Tin Plate Company, and successively held the positions of power foreman and electrical engineer of construction. He was later appointed to the position of assistant superintendent of maintenance, and subsequently to his present position of superintendent of the electrical maintenance department at the Sheet and Tin Mill Plant of the Carnegie-Illinois Steel Corporation, Gary, Indiana.

W. H. Collison was graduated from the University of Cincinnati in 1926 with a degree of chemical engineer. This was a cooperative course during which he worked in the coke plant of Pittsburgh Crucible Steel Company, beginning in 1924 and continuing after graduation until 1927. He then went to Central Alloy Steel Corporation, Massillon, Ohio, as heater in the coke plant, and was made turn foreman shortly thereafter. In 1935, Mr. Collison went with the Pure Oil Company, Marcus Hook, Pennsylvania, as a chemist. Following this he came to Detroit as boss heater for the new coke plant of Great Lakes Steel Corporation, being subsequently promoted to assistant superintendent and later to superintendent of the coke plant.

Norman C. Bye, chief engineer of the Henry Disston and Sons, Inc., Philadelphia, Pennsylvania, is serving his second term as chairman of the Philadelphia District Section. Mr. Bye was born in Philadelphia, and, after graduation from the University of Pennsylvania, went with the Philadelphia Electric Company. In 1918, he began work for the Disston company as combustion engineer. He subsequently served several years in the construction department and as assistant metallurgist, being appointed to his present position in 1926.

H. R. ZIMMERMAN

W. H. COLLISON

NORMAN C. BYE

WISCONSIN STARTS NEW OPEN HEARTHS

▲ On September 16, steel was first poured from a new 150 ton open hearth furnace at the Wisconsin Steel Works of the International Harvester Company, Chicago, Illinois. This furnace is one of two new ones built to increase the ingot capacity of the steel works. The two new furnaces were among the first to be authorized after national defense needs caused the government to seek an expansion of the nation's steel-making capacity, and will add about 160,000 tons of steel per year.

Making all possible haste because of the need for additional steel, the construction job was completed in eight months from the time of authorization, 45 days ahead of schedule. Erection work was finished in time, despite abnormal materials procurement and construction conditions. In order to expedite completion of the two new furnaces and auxiliary equipment, many items were fabricated and assembled in the plant.

Complicating the construction work was the location of the two new furnaces at the east end of the existing open hearth building, adjacent to the Calumet River. Difficult problems had to be met by the construction men and the men operating the existing furnaces, to avoid serious interruptions in plant operations.

The new furnaces are rated at 150 tons, and are 70 ft. overall length, 44 ft. 1 in. long, knuckle to knuckle. Overall width is 22 ft., and sloping backwalls are provided. The furnaces are fired with preheated mixed blast furnace and coke oven gas, through retractable gas ports of the Rose type.

Air and gas checker chambers and slag pockets are fully insulated and encased. Control of fuel-air ratio and furnace pressure is provided, by Askania automatic controls, and furnaces are reversed on a differential checker temperature schedule as measured by Leeds-Northrup potentiometers.

In addition to the two new open hearths, a 220 ton crane, a charging machine, and a 2 hole soaking pit were also included in this expansion program. The soaking pits, built to increase heating capacity for the blooming mill, are of Amsler-Morton design, with mixed blast furnace and coke oven gas introduced through the center of the furnace bottom, exit gases passing through a tile recuperator. Automatic fuel-air ratio and temperature controls are provided. Pit covers are handled by a low traveling crane mechanism. Each pit is 11 ft. x 16 ft. in size, with an approximate capacity of 75 tons of ingots.

George E. Rose, vice president, and W. E. Brewster, assistant general superintendent, watch the making of the first heat in Wisconsin's new open hearths.

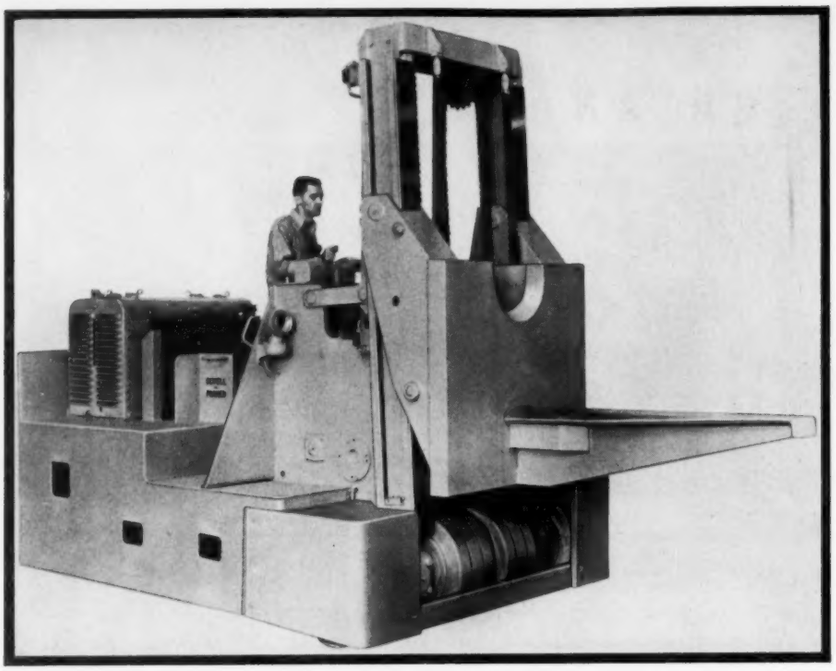
ANNOUNCES NEW RAM TRUCK MODEL

▲ The Elwell-Parker Electric Company has recently announced the development of a new ram truck with a rated capacity of 25,000 lb. It is the first of a new series of extra heavy duty ram trucks developed by the company, and is the first truck within this range of capacity to have the drive under the load end of the truck.

It has four wheels, arranged in pairs, across the front. Each pair supports the frame on pivots or is articulated so that wheels conform to floor irregularities. All four wheels are provided with hydraulic brakes and new method arranging oil lines.

One wheel of each pair is driven by means of long center roller chain from motor driven differential bearing axle, accessibly located forward of power or battery deck.

In bringing out this model, Elwell-

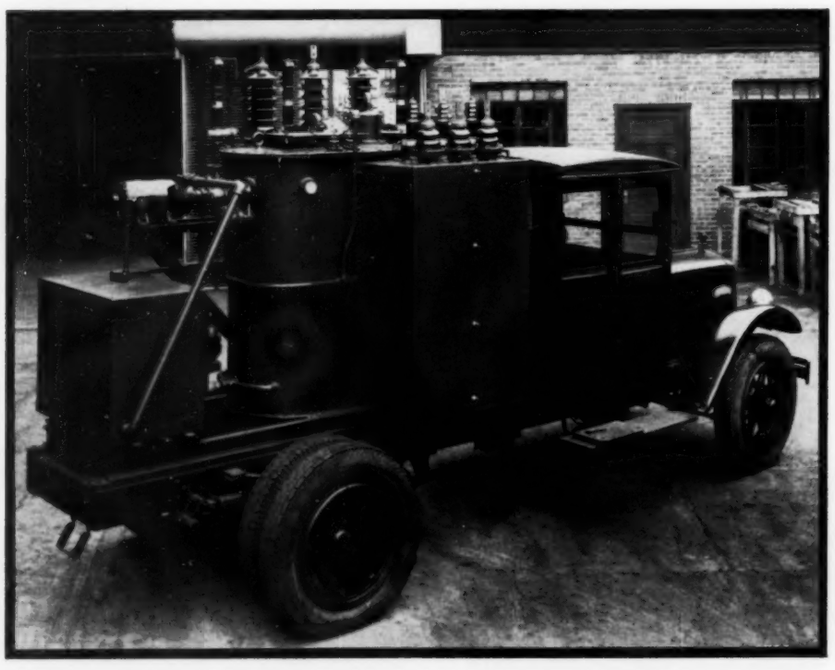


This truck, the first of a new series, has the drive under the load end of the truck.

Parker is working on a new theory for heavy duty ram trucks insofar as using the drive axle to drive the truck only, the weight of the truck being completely supported by the articulated driven wheels, thereby reducing dead weight, still assuring traction whether loaded or empty. By locating uprights over drive wheels the load stresses on carriage and uprights require less material for same rated capacity. Trail axle is pivoted in frame affording, with drive axle, a full three point suspension of frame.

Equipment includes extra heavy drive and power plants, full magnetic contactor control on all operations, and follow-through type power steer. It is of all welded steel construction throughout.

This truck affords more accessibility to the working parts of the equipment than most trucks of its type, due to its unique design in the driving mechanism. The entire axle assembly can be made available for complete inspection within a few minutes. The wheel guards are placed around the two outside wheels and an extra heavy bumper channel across the entire front of the truck to protect the tires from any projecting objects. These guards clear the floor by about 3 in.



This mobile substation, weighing 10,500 lb., has a capacity of 500 kva., with variable voltage step-down.

▲ Designed and built to meet very rigid limitations of weight, height, etc., a mobile substation for a large eastern utility company was supplied by Pennsylvania Transformer Company, Pittsburgh, Pennsylvania. This unit, rated at 500 kva., 3 phase, 60 cycles, was designed for 33,000/22,000 volts primary, delta connected, and for 2300/4600/6900 volts secondary, delta connected, and 4000/8000/11,950 volts, Y-connected.

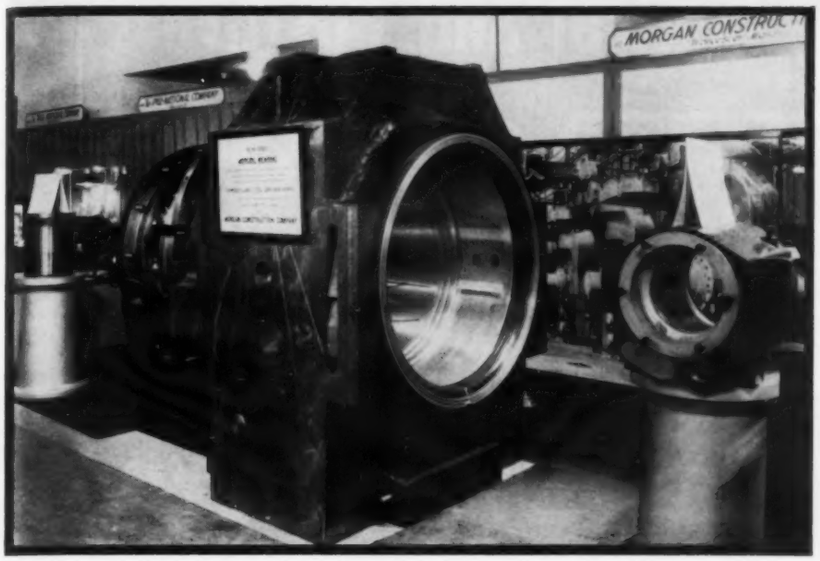
The high voltage side of the transformer is equipped with three 33 kv. lightning arresters and a 3 phase single-throw disconnect switch, complete with Corey key interlock for mechanical interlocking with the low voltage circuit breaker. The switch will interrupt exciting current at 33 kv.

On the low voltage side the transformer is provided with three 12 kv. lightning arresters; three single-pole single-throw disconnect switches rated at 250 amperes, 12 kv.; one 3 phase 12 kv. oil circuit breaker interlocked with the high voltage disconnect switch; two current transformers for ammeters and low voltage breaker overload trip; and three ammeters showing currents on the low voltage side.

Terminal boards are provided for changing transformer windings from series to multiple and from star to delta. The high voltage winding is provided with a tap changer for the regulating taps.

A pump draws off hot oil from the top of the transformer, passing it through a cooler of fin-tube design with a 4-blade aluminum fan. The cooled oil then enters the bottom of the tank through two headers placed to give efficient circulation through the transformer coils.

Total weight of the unit is 10,500 lb., approximately 5000 lb. lighter than the average self-cooled transformer of equal capacity.



BACK-UP BEARINGS TAKE HIGH LOADS

▲ Forty-four Morgoil back up roll bearings used on back up rolls of large cold mills in two plants of a large steel corporation in the Chicago and Pittsburgh districts have now been in successful operation for some time. The first two installations in the Chicago district were made in 1936 and the third installation in the Pittsburgh district in 1938.

These bearings are used on tapered necks 39 in. diameter and on straight necks 38 in. diameter. The journal diameter is 44 in., the length of journal 39¾ in. The continuous full load carrying capacity of each bearing is 5,247,000 lb. resulting in a total mill separating force capacity of 10,494,000 lb. This capacity is sustained throughout the speed range of these mills.

These bearings are in all probability 25 to 30 per cent greater in capacity than any roll neck bearing of any type which has ever been built. Each bearing, exclusive of its chock, weighs 12,500 lb. and with the chock the weight per bearing is approximately 42,200 lb.

One of these bearings was exhibited at the Iron and Steel Exposition in Cleveland in 1938, by Morgan Construction Company of Worcester, Massachusetts.

IRVIN COLD MILL WORLD'S FASTEST

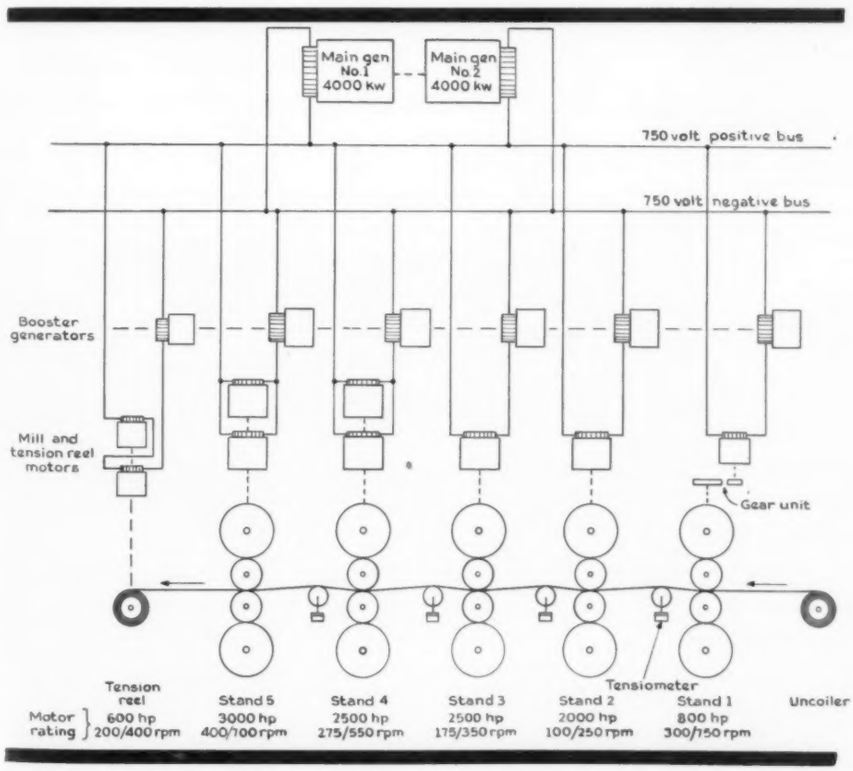
▲ A new 5-stand cold strip mill incorporating a number of "firsts" in electric drive and control for steel mills has recently been put into operation at the Irvin Works of the Carnegie-Illinois Steel Corporation, at Pittsburgh, Pennsylvania. The highest-powered cold-rolling mill for tin mill products in the world, it has been operated at a delivery speed as high as 3750 ft. per min. and is capable of 3850 ft. per min. without exceeding the specified ratings of the mill driving motors.

The new mill was placed in operation approximately nine months after the equipment was first ordered. Successful operation of the mill was obtained immediately after starting the mill in production.

A total of 11,400 hp. is employed to drive the mill. Stands 1, 2, and 3 are driven by direct-current motors rated 800, 2000, and 2500 hp. respectively. Stands 4 and 5 are driven by double-armature d-c. motors of 2500 and 3000 hp. respectively. For driving the tension reel a 600 hp. double-armature motor is employed. All of these motors are of the special mill type, designed by General Electric Company with particular attention paid to their armature stored-energy characteristics.

Even more spectacular as to size are the two G-E 4000 kilowatt generators—largest d-c. generators ever built—which supply power to the main mill motors and tension reel at 750 volts direct current. The driving motor of the motor-generator set is an 11,300 hp. synchronous motor operated at 6600 volts.

To reduce any voltage fluctuations on the main 6600 volt system which might be caused by load changes on the main motor-generator set, a reactive kva. regulator is used. This regulator controls excitation of the



Schematic arrangement of new cold mill at Irvin Works, in which several unusual features are incorporated.

For Perfect Braking Control and Positive Parkin

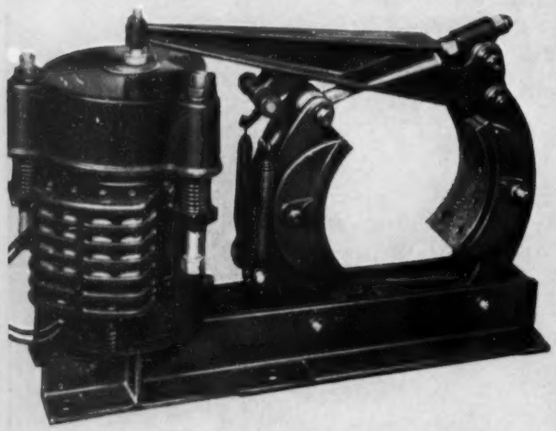
Use WAGNER HYDRAULIC BRIDGE BRAKES on coke-oven machinery

Door machine equipped with Wagner type HM Hydraulic Bridge-Brakes. Photo courtesy of the Wellman Engineering Corporation.

Coal-charging car equipped with Wagner type HM Hydraulic Bridge-Brakes. Photo courtesy of the Wellman Engineering Corp.

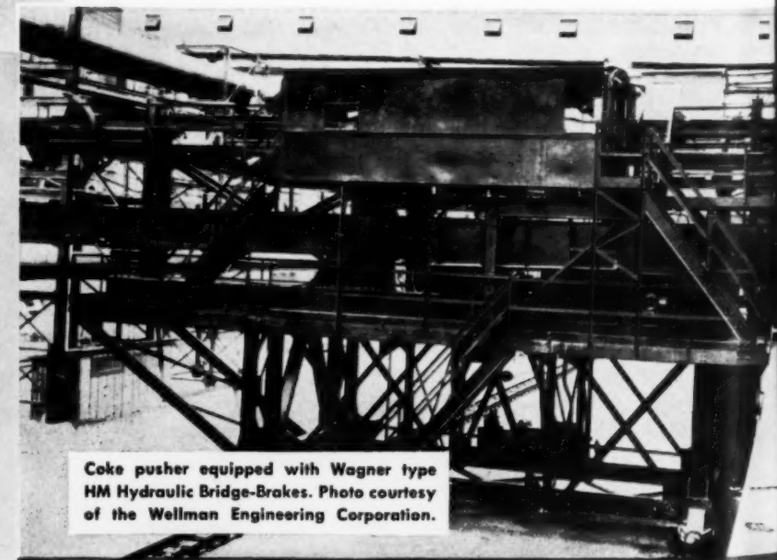
Quick, accurate stopping of coal-charging cars, coke pushers, and door machines is important in all coke plants and particularly so on the newer ovens which require extremely close spotting.

Wagner Type HM hydraulic bridge-brakes are well suited for application to coke-oven machinery. The hydraulic service-brake insures accurate spotting and the automatic parking-brake provides a positive brake which holds the machine in position while charging, pushing, or when not in service.



TYPE HM

Wagner Hydraulic Bridge-Brake with automaticparking attachment.The ideal brake for all coke-oven machinery.



Coke pusher equipped with Wagner type HM Hydraulic Bridge-Brakes. Photo courtesy of the Wellman Engineering Corporation.

SEND FOR BULLETIN IU-20

This bulletin gives you complete information on Wagner Bridge-Brakes and should be in the hands of all production, safety, and maintenance superintendents. Write for your copy today.

Wagner Electric Corporation

6400 Plymouth Avenue, Saint Louis, Mo., U.S.A.

BRAKES • FANS • TRANSFORMERS • MOTORS

1414

VOLTAGE & VICTORY

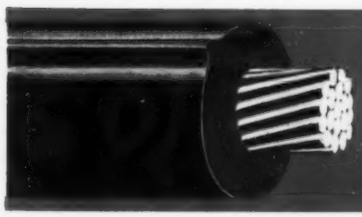
The two are inseparably linked by the needs of a mechanized world . . . needs that may demand a single cable insulated for 220,000 volts and with capacity enough to supply the electric power for an average city or major industrial center.

Cables that will withstand oil . . . or sunlight . . . or excessive heat . . . or chemical action.

Cables for the navy . . . for the army . . . submarine power cables . . . electric lines for boiler rooms . . . railway signal wires whose reliability must be unquestioned . . . flexible "cords" two or three inches in diameter, to string along the ground to the monster shovels that scoop up tons of coal at a bite . . . supple welding cables . . . all these and dozens more, large and small, are found in the list of cables we supply to industry, to transportation and to central stations.

For this work, our organization, through its Engineering Service, combines an experience of over 60 years, unique manufacturing methods, a research organization completely staffed and equipped for the work and production facilities which enable us to manufacture every type of insulated wire and cable.

Detailed information as to proper design and specifications of cables for particular applications will be gladly furnished on request by The Okonite Company, Passaic, New Jersey. Offices in principal cities.



OKONITE

OKONITE

INSULATED WIRES AND CABLES

(*Continued from page 95*)
synchronous motor by an amount dependent upon the load on the motor-generator set.

In addition to variable-voltage control of the mill motors, each motor has a series booster generator to compensate for the armature circuit resistance voltage drop. Operating at a voltage proportional to the load on the mill motors, these boosters aid in maintaining uniform strip tensions between mill stands even during rapid acceleration and deceleration of the mill.

To operate the mill at the high speeds involved, and to accelerate or decelerate it very rapidly with metal in the rolls, G-E precision cold strip mill control is employed. Amplidynes play a big part in this system, handling the various control functions without the aid of other regulators.

Amplidyne control of the main generator voltage provides a means of raising and lowering the bus voltage and of maintaining the voltage at a preset value independent of generator load. An amplidyne exciter controls each of the mill motor booster generators, providing for accurate and rapid response of the booster generators to the mill motor load. Another amplidyne exciter controls the tension reel motor to hold a practically constant strip tension while the strip is being wound on the reel drum.

Installed between the five stands are four indicating tensiometers which enable operators to read the actual pounds of strip tension as the strip proceeds through the mill. Tapered tension control of tension between stands provides for a more uniform finishing gage at lower strip speeds. Automatically, at low strip speeds, this control system permits the tension to be increased so that the finished strip may be "on gage."

IS HEAT SLOWING UP YOUR WORKMEN?

TRUFLO CRANE CAB FANS
For cooling interiors of crane cabs and other confined areas. Adjustable both horizontally and vertically. Four blade type, 12 and 18 inch sizes.

Keep Them COOL with TRUFLO FANS

TRUFLO PORTABLE COOLING FANS
Easily portable. Help keep efficiency high where work is hottest. 12 to 36 inch diameters.

Production suffers when workmen are overheated. Steps begin to drag, efficiency falls.

Now, when speedy production is vital, Truflo Fans can help keep your workmen on their toes. All Truflo Fans are designed and built correctly to put fresh cool air *in large volumes* exactly where it is needed. Perfectly-balanced shafts and blades give more air per h.p. . . . strong steel frames stand up longer under hard use . . . rugged wire guards protect men against injuries.

All of the following types can help beat the heat, keep production moving in your plant. Write for illustrated literature.

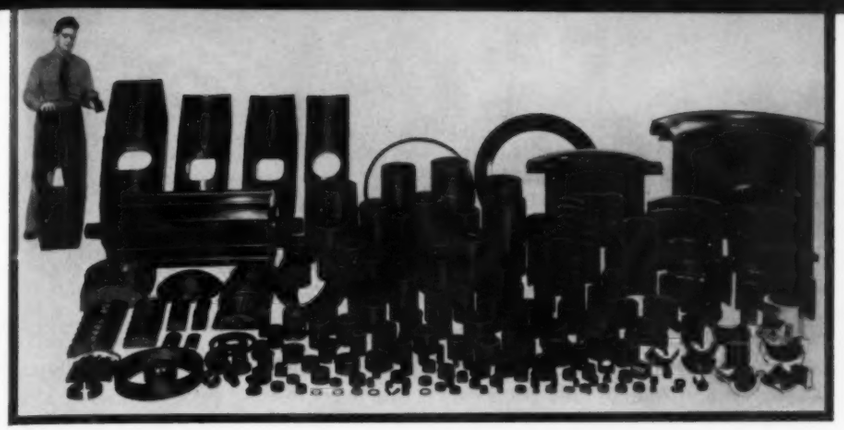
PORTABLE COOLING FANS
CRANE CAB FANS • WALL FANS
EXHAUST FANS • BLOWERS
ROOF VENTILATING FANS
PENT HOUSE FANS

TRUFLO FAN COMPANY
554 MAIN ST., HARMONY, PA.

NEW LOCOMOTIVE HAS DUAL DIESEL ENGINES

▲ The H. K. Porter Company, Inc., Pittsburgh, Pennsylvania, announces recent completion of a new 65 ton, double power plant locomotive for general industrial and switching use. Powered with two Cummins supercharged diesel engines developing 200 hp. each, the locomotive has a tractive force of 39,000 lb. at 30 per cent adhesion. Overall size is 12 ft. high by 9 ft. 6 in. wide by 33 ft. long, from bumper to bumper. Total weight, in working order, is 130,000 lb. The locomotive is built for both standard and 36 in. gauge track.

Each engine is fitted with a fuel distributor, forced feed lubrication, centrifugal cooling pump and a 32 volt automotive type starting motor with 350 volt generator. Radiators, engines and generators are mounted on bedplate of heavy steel construction, designed so that the entire unit with bedplate can be removed readily. Main frames are fabricated in an extremely rugged manner, to offset the hard use encountered in industrial service.



FABRIC BEARINGS FOR STEEL PLANTS

▲ Fabric bearings, specially engineered for the application and made of many different material combinations to meet service conditions, are giving excellent results on service ranging from blooming mill roll necks, where heavy shock loads and frequent reversals are encountered, to conveyors, where smooth, dependable operation is important. The accompanying illustration shows some of the various shapes and sizes of fabric bearings, moulded to finished dimensions, which are supplied by the Gatke Corporation, Chicago, Illinois.

Special advantages offered by fabric bearings are smooth wearing surfaces and low frictional coefficient, resulting in good wear life and reduced power consumption; hardness that approaches steel, yet will not score journals—even if lubrication fails for limited periods, journals will not be damaged; a tough, resilient structure that withstands great shocks and repeated blows without fatigue; can be adequately lubricated at pressures and speeds where lubrication breaks down with ordinary metal bearings; not affected when grease or oil lubricant is diluted with water; highly resistant to weak acids and weak alkalis; made in three types for grease or oil lubrication, water lubrication, and for some unlubricated applications.

In plant after plant, installations on troublesome applications have overcome chronic difficulties and effected such good results that the extensive use of fabric bearings has naturally followed.

REPUBLIC TO EXPAND PIG IRON CAPACITY

▲ The nation's pig iron capacity will be increased by nearly 1,750,000 tons annually with the completion of a program announced in Washington by Defense Plant Corporation, and confirmed by Repulbic Steel Corporation.

Included in the program are four blast furnaces, 276 by-product coke ovens, increased sintering, concentrating and by-product capacity and expansion of both iron ore and coal mining operations and installation of a vast amount of auxiliary equipment of all types.

These facilities will be paid for and owned by Defense Plant Corporation and will be operated by Republic.

The corporation's present blast furnace capacity is 4,870,000 tons. The blast furnaces will be increased from 17 to 21. By-product coke ovens will be increased from 786 to 1062.

The improvements will affect widely scattered areas ranging from northern New York State to Birmingham, Alabama. Benefited by the program will be Cleveland, Youngstown, War-

CONDULETS
MANUFACTURED ONLY BY
CROUSE-HINDS

The Standard of Quality in the field of electrical conduit fittings.

Every **CONDULET** bears the trade mark of the Crouse-Hinds Company

A Nationwide Distribution Through Electrical Wholesalers

CROUSE-HINDS COMPANY
SYRACUSE, N. Y., U. S. A.

Sales Offices: Birmingham — Boston — Chicago — Cincinnati — Cleveland — Dallas — Detroit — Houston — Kansas City — Los Angeles — Milwaukee — Minneapolis — New York — Philadelphia — Pittsburgh — San Francisco — Seattle — St. Louis — Washington
Resident Salesmen: Albany — Atlanta — Baltimore — Buffalo — Charlotte — Denver — Louisville — New Orleans
CROUSE-HINDS COMPANY OF CANADA, LTD., *Main Office and Plant:* TORONTO, ONT.

ren, Ohio; Gadsden and Birmingham, Alabama; and Port Henry, New York.

Following is a list of improvements:

Cleveland—Two 1275 ton blast furnaces (annual capacity approximately 900,000 tons) duplicates of the corporation's Warren blast furnace, rated as the largest in the world; two batteries of coke ovens of 75 ovens each, with a by-product recovery plant; additional dock facilities for iron ore handling.

Youngstown—A 1120 ton blast furnace (annual capacity approximately 392,000 tons).

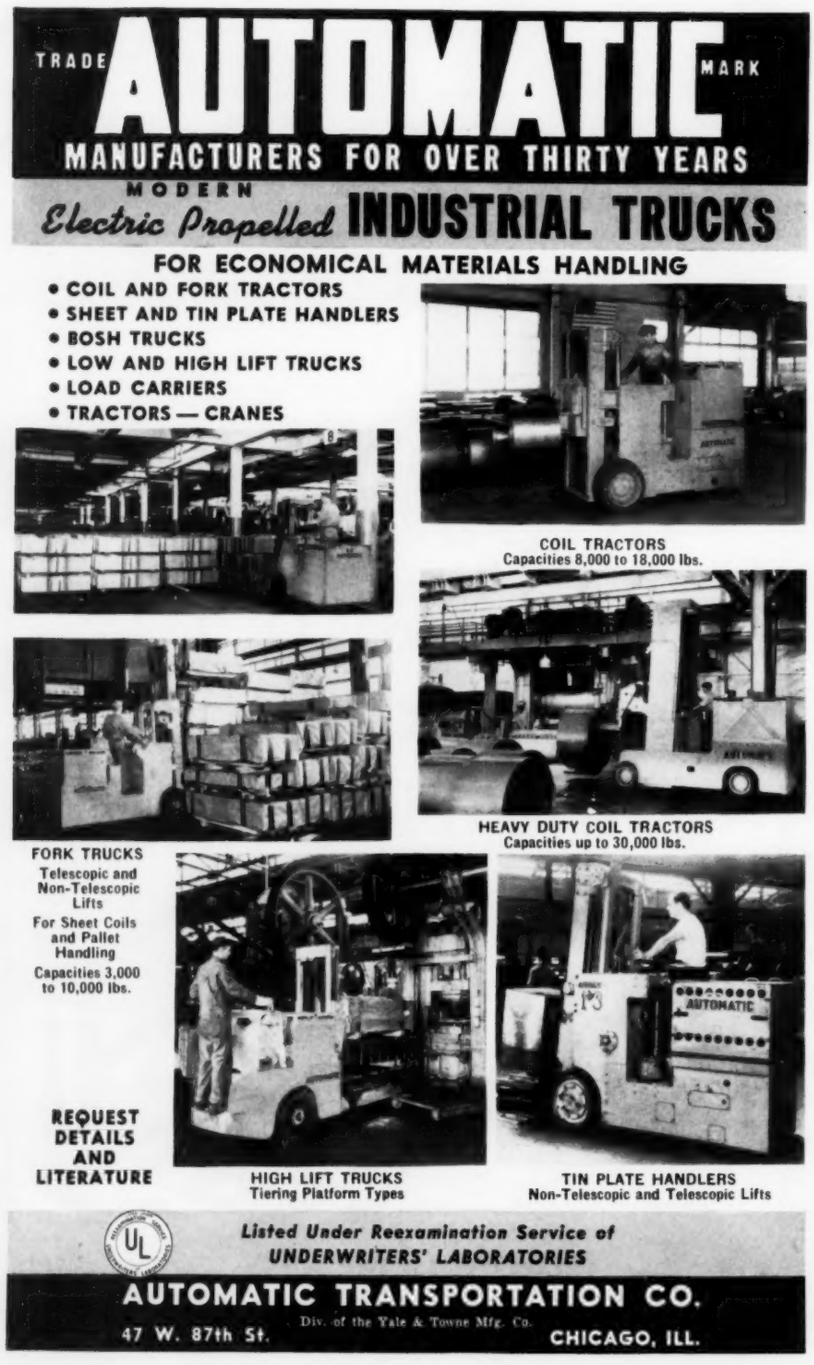
Gadsden, Alabama—An 800 ton blast furnace (annual capacity approximately 280,000 tons); battery of 65 coke ovens, with by-product recovery and benzol plants; enlarged coke wharf.

These four furnaces will produce approximately 1,572,000 tons annually. The balance of the increase will come from use of high iron content Port Henry sinter in existing furnaces in the Mahoning Valley.

Birmingham, Alabama—Enlarged concentrating plant and a sintering plant at Spaulding ore mine, and reopening of Sayre coal mine.

Warren, Ohio—Sixty-one coke ovens; a new coke wharf, coke handling equipment, coke screening system, and a new by-product building; and a sintering plant to handle an increased volume of iron ore.

Port Henry, New York—New ore shaft at Fisher Hill, together with hoisting and crushing equipment and a concentration plant with a 1,000,000 ton annual capacity.



Auxiliary Equipment

New locomotives and railroad cars will be purchased for the new plants to handle the greatly increased tonnage.

An important advantage, in addition to the increased iron tonnage mostly for steel-making, which will be gained from the expansion, will be the expansion in the production of basic materials needed in the manufacture of medicines and explosives from coke by-products.

Other Expansions

T. M. Girdler, Republic Chairman, pointed out that the pig iron expansion program is Republic's fourth major step during 1941 in providing facilities for defense. The other three improvements are:

Electric furnaces, either installed or building, have been increased from six to 15. Steels vital to airplane and tank production come from the electric furnace.

Installation of a light armor plate plant now producing 7000 tons a month. Armor plate for 200 tanks monthly is finished, shaped and treated, and the balance is processed by the manufacturer.

Facilities now being provided for an additional 220,000 tons of plates annually bring the corporation's output to 600,000 tons. Plates are used in ships, tanks, combat cars and other defense essentials.

Construction is to begin at once and most facilities will be in operation in a year.

INLAND'S PIG IRON OUTPUT TO INCREASE

▲ The Inland Steel Company has today signed a contract with Defense Plant Corporation for new facilities to be built at East Chicago, Indiana, as a part of the national defense program.

The plan involves the construction of two blast furnaces having an estimated pig iron capacity of 900,000 tons per year, together with the supporting coke ovens, by-product plant, docks, and auxiliary equipment.

The plant will be paid for and owned by Defense Plant Corporation, with the Inland company acting as the agent for the government in the carrying out of the construction program. The Inland company will receive no compensation whatever for its services.

When the plant is ready for production, it will be leased to the Inland company for operation.

The Inland company has no option to purchase the plant at the conclusion of the emergency.

A definite site has not yet been purchased. It will be adjacent to the present Inland plant, but outside the boundaries of that plant, so that at the close of the emergency it will constitute a self-contained unit which the government may dispose of on the best terms obtainable.

The work of preparing plans and specifications is already actively under way.

NEW STARTERS OFFER CIRCUIT PROTECTION

▲ A new line of 2300-volt 60-cycle general purpose starters especially designed for protection against short circuits and overloads has been announced by the Industrial Control Division, General Electric Company, Schenectady, New York. Composed of an oil-immersed contactor with self-cleaning copper tips, wide metal bearings, and copper-braided shunts for long life, and the new EJ-2 current-limiting fuses for short circuit protection, the control and bus structure is completely metal-enclosed for compactness, easy installation, and safety.

There are four standard types of starters in this new line—providing for full-voltage starting, reduced-voltage starting, and reversing of squirrel-cage motors and synchronous motors. Starters for special applications are also available.

These starters afford complete protection against short circuits by the use of EJ-2 current-limiting fuses, which limit short circuit current in less than ¼ cycle, and open in less than ½ cycle. These fuses have a disconnect feature which makes possible the complete isolation of an individual starter without causing the entire motor line to be shut down.

Motors are protected against overloads by isothermic relays which operate in case of locked rotor, single-phasing, or sustained overload. Under voltage protection is provided; on low voltage or loss of power the line contactor opens and on return of power the motor will not restart until the push button is operated.

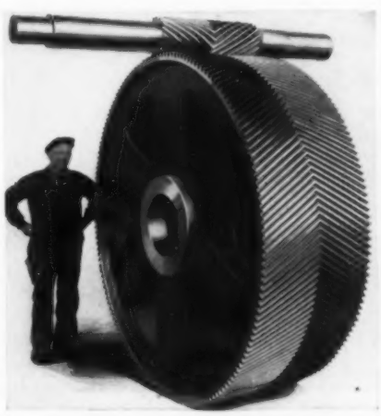
FARREL-SYKES GEARS
for Rugged, Smooth Running
ROLLING MILL DRIVES

Farrel-Sykes Gears for rolling mill drives meet today's defense production demands for ruggedness, for ability to withstand the shocks, stresses and wear incident to high speeds and heavy loads, and for efficient, trouble-free performance.

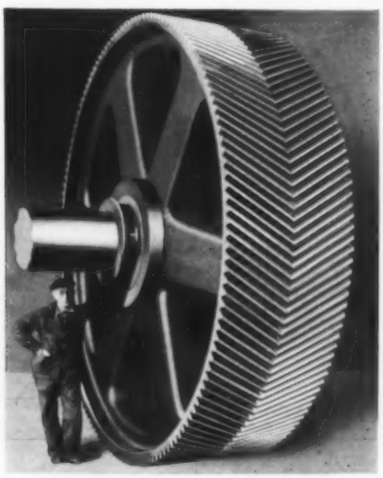
With the greater bearing surface provided by their continuous herringbone teeth, Farrel-Sykes Gears are stronger and better able to carry heavier loads at high speed. In consequence, they offer the advantages of reduced weight and size for a given load requirement, together with exceptionally quiet, smooth-running operation.

Due to the interlacing and creeping engagement of their teeth and inclined line of pressure, Farrel-Sykes Gears are better able to withstand wear. And their involute profile and correct tooth action are maintained as long as the gears last. Furthermore, their opposed helices balance and absorb axial thrust within the gear member, eliminating harmful thrust loads and resultant stresses on other parts of the machinery.

These are but some of the many features that account for the long-lived, economical performance of Farrel-Sykes Gears for rolling mill drives. Farrel engineers are always available for consultation on gear problems.



High ratio gears for a rolling mill drive. In the limited space available only continuous tooth herringbone gears were able to meet the requirements.



Continuous tooth herringbone gear for rolling mill drive, 5,000 HP, weight 61,700 lbs., 145" diameter, 145 teeth, 1 DP, 40" face.

FARREL SYKES GEARS
FARREL-BIRMINGHAM COMPANY, Inc.
ANSONIA, CONN. - - - - - BUFFALO, N. Y.
The Gear with a Backbone

NEW COKE PLANT FOR SOUTH AMERICA

▲ Koppers Company of Pittsburgh, Pennsylvania, has been awarded a contract for a complete by-product coke plant, consisting of 55 Becker type coke ovens, including a plant for the recovery of ammonia, tar, benzol, toluol, etc., for Companhia Siderurgica Nacional (Brazilian National Steel Company) at Volta Redonda, near Rio de Janeiro, it was announced by Joseph Becker, vice president of Koppers Company. The contract was said to involve approximately $3,000,000.

This plant is to be built in connection with a blast furnace and steel plant. The contract was negotiated with Lt. Col. E. Macedo Soares e Silva, Technical Director of the above named company, with offices at Cleveland, Ohio, and Arthur G. McKee and Company, builders of blast furnaces and steel plants, at Cleveland, Ohio, who are the engineers for the entire steel works.

15TH ANNIVERSARY

CLEVELAND *All-Welded* CRANES

25 ton-90'-0" span Cleveland all-welded crane in a modern steel mill

MODERN CRANES ARE

ALL-WELDED

Not just the trolley or the end trucks, but every section of modern cranes is all-welded — including the girders.

It stands to reason that if welding improves some sections of a crane it will improve all sections. For this reason Cleveland has been **all-welding** cranes since 1926.

A large part of the hundreds of all-welded cranes we have built are serving the steel industry. To the best of our knowledge, every all-welded Cleveland crane is still on the job performing like it did the first day installed.

THE CLEVELAND CRANE & ENGINEERING CO.
Wickliffe, Ohio

CLEVELAND CRANES

ALL-WELDED OVERHEAD TRAVELING CRANES

Other products: CLEVELAND TRAMRAIL and STEELWELD MACHINERY

NEW LITERATURE AVAILABLE

▲ United Engineering and Foundry Company, Pittsburgh, Pennsylvania, has just issued an attractive catalog, "United Bloom, Slab and Section Shears." In addition to portable utility shears, lever shears, vertical shears, horizontal shears, upcut shears, downcut shears, etc., the publication lists the new design of "down and upcut" shears, which was featured by a model in the company's booth at the 1941 Iron and Steel Exposition in Cleveland, Ohio.

▲ In "True Steel," a recent publication from Bobbs-Merrill Company, the author, Christy Borth, presents an interesting story of the life of George M. Verity and his associates in the American Rolling Mill Company. Coinciding and interwoven with this readable story is a resume of the development of the iron and steel industry in general, and of Armco in particular. Emphasis is placed on the growth of the three-point policy of Armco: consideration of employees as partners in a common enterprise, responsibility of the company to the community, and the importance of technological research.

The book contains an interesting reference to the Association of Iron and Steel Engineers: "In 1907, almost a year before Roosevelt started shouting for reform, the Association of Iron and Steel Electrical Engineers was formed, and set up, at its first meeting, a safety committee to study the new hazards introduced into steel mills by the increased use of electricity. This was probably the first industrial safety committee in the United States. . . .

"Meantime, Superintendent Hook had launched his company's private war on work hazards. Two years after he began it, he was able to report encouraging results when the Iron and Steel Electrical Engineers invited him to attend their famous Milwaukee meeting which was the world's first safety congress and the origin of the National Safety Council.

"For full significance of this pioneering, statistics speak eloquently. In 1913, when the program began to become nation-wide in scope, 35,000 died in industrial accidents in the United States. By 1937, though total employment had multiplied many

times and industrial mechanization introduced millions of new hazards, the total had fallen to 19,500."

▲ Allis-Chalmers Manufacturing Company, Milwaukee, Wisconsin, has just issued an eight-page bulletin (B6052-B) which concisely describes the complete line of the company's Lo-Maintenance Motors in ratings from ¾ to 75 hp., open, enclosed and splash-proof types, a-c. and d-c.

▲ Special refractory shapes cast right in your own plant and ready for use within 24 hours is the solution offered to delivery delays on special shapes and the possibility of costly shutdowns in a folder on Firecrete and other castable refractories just issued by Johns-Manville. These hydraulic-setting refractories are described as suitable for door and other linings, burner rings, furnace bottoms, and special refractory shapes. The tabular data included in the folder shows three types of Firecrete with temperature limits of 2200, 2400, and 2800 degrees F. and chrome castable for temperatures to 3200 degrees F.

Copies of the folder, Form RC-13A, are available upon request to Johns-Manville, 22 East 40th Street, New York, New York.

▲ Many typical uses are pictured, and savings are given for principal classes of work, in the new Hypressure jenny steam cleaner catalog being issued by the Homestead Valve Manufacturing Company.

Other information in the catalog includes principle of operation, model specifications, and information to aid in the selection of the right model hypressure jenny to handle the broadest range of each customer's cleaning jobs.

▲ Direct-current motors for service in mines, mills and general industry is described in a new 8-page booklet announced by the Westinghouse Electric and Manufacturing Company.

Several recent improvements; namely, sealed-sleeve bearings, rigid frame-and-foot design, directed ventilation, and adjustable brushholders are discussed along with a pictorial description of each.

The reduction of maintenance with form-wound, mica-insulated armature coils and the safeguarding of field coils with breakdown-proof insulation are also described in this new piece of literature. The frames and enclosures for every type of service are explained and illustrated.

A copy of descriptive data 4004 may be secured from department 7-N-20, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pennsylvania.

▲ The Bull Dog Electric Products Company announce their latest Bulletin 412 illustrating and describing the new Bull Dog LO-X (low reactance type) Bus Duct.

This is a new design feeder type duct for large ampere capacities. Heretofore it has been necessary to enclose the large capacity busbars in aluminum casings to reduce reactance. In view of the present shortage of aluminum we redesigned our large capacity feeder type Bus Duct so that we can now use a steel casing or duct and yet reduce the voltage drop from reactance, to an even greater extent than was possible using aluminum casing.

BETTER RESULTS IN FURNACE OPERATION with HAYS INSTRUMENTS

SUPERSENSITIVE DRAFT RECORDERS SERIES "OT" You can make sure of BALANCED Draft Conditions in Open Hearths, Soaking Pits, Annealing Furnaces and Slag Mills by installing Hays Series OT Recorders.

These instruments give a correct indication of furnace atmospheres and a permanent record of pressures and drafts at vital points as guides for most effective operation.

Write for descriptive bulletin.

PATENTS PENDING. This gage is calibrated in terms of air and gas flow—but may be used for any two flows for which the instrument is calibrated.

HAYS VISIO-RATIO GAGE

3 INSTRUMENTS IN 1 . . . 1. Air-Flow Indicator . . . 2. Fuel-Flow Indicator . . . 3. Ratio Indicator. Shows at a glance the exact ratio existing between flow of gas or flow of oil or other measurable fluid: pressure, draft, suction, temperature (up to 1000° F.) speed in R.P.M. or inches per minute, position, level and others.

This newest Hays instrument is a guide to higher manufacturing efficiency, increased production, better products and lower costs. It shows relations at a glance and eliminates the necessity of making calculations to determine excess or deficiency.

If you will write us, stating the conditions, we will tell you exactly how the Hays Visio-Ratio Gage can be applied to your problem.

The HAYS CORPORATION
COMBUSTION INSTRUMENTS AND CONTROL
MICHIGAN CITY, INDIANA, U.S.A.

NEW MEMBERS

Active

EDWIN BALL
Electrical Engineer
Bethlehem Steel Company
Lackawanna, N. Y.

M. E. CUSICK
District Industrial Engineer
Republic Steel Corporation
Gadsden, Alabama

A. G. HENRY
Superintendent of Maintenance
Tennessee Coal, Iron and Railroad Company
Fairfield Tin Mill
Fairfield, Alabama

A. J. GLYNN, JR.
Sub-Station Operator
Electrical Department
Jones and Laughlin Steel Corporation
Pittsburgh, Pennsylvania

C. G. DAVIES
Manager, Hot and Cold Sheet Departments
Richard Thomas and Company, Limited
Ebbw Vale, Monmouthshire, England

R. L. SHEETS
Chief Electrician
Pittsburgh Coke and Iron Company
Pittsburgh, Pennsylvania

R. H. FERGUSON
Manager Safety
Republic Steel Corporation
Cleveland, Ohio

H. A. LUNDSTROM
General Foreman
Electric Repair Shop
Carnegie-Illinois Steel Corporation
Gary, Indiana

L. E. SMITH
Chief Engineer
Continental Steel Corporation
Kokomo, Indiana

T. E. GRAINE
Chief Electrician
Pittsburgh Coke and Iron Company
Sharpsville Blast Furnace Plant
Sharpsville, Pennsylvania

H. O. LINDE
Design Engineer
Carnegie-Illinois Steel Corporation
Gary, Indiana

W. E. GERSTMEYER
Assistant Roller, 93 in. Tandem Mill
Great Lakes Steel Corporation
Ecorse, Michigan

GEORGE C. ANDERSON
Electrical Engineer
Maintenance Department
National Tube Company
McKeesport, Pennsylvania

O. A. BAMBERGER
Superintendent Mechanical Department
Republic Steel Corporation
Massillon, Ohio

W. H. BOUGHER
Employment Manager
Wheeling Steel Corporation
Steubenville, Ohio

T. M. BRUBACK
Appropriation Control Engineer
Carnegie-Illinois Steel Corporation
Gary, Indiana

R. E. CRAMPTON
Electrical Test Engineer
Republic Steel Corporation
Chicago, Illinois

D. H. CRUMBAUGH
Bench Board Operator
Power Production
Carnegie-Illinois Steel Corporation
Gary, Indiana

S. DAS GUPTA
Assistant Master Roll Turner
Tata Iron and Steel Company
Jamshedpur, India

D. I. DILWORTH
Superintendent, Seamless Pipe Finishing
National Tube Company
McKeesport, Pennsylvania

P. J. DOYLE
Lubrication Engineer
Republic Steel Corporation
Cleveland, Ohio

C. L. DUDLEY
Superintendent Steam Department
Jones and Laughlin Steel Corporation
Aliquippa, Pennsylvania

E. E. ECKSTROM
Mechanical Maintenance Foreman
Pump Station and Gas Washers
Carnegie-Illinois Steel Corporation
Gary, Indiana

J. D. ELDER
Chief Engineer
Crown Cork and Seal Company
Baltimore, Maryland

J. E. ERHARDT, JR.
Mechanical Engineer
Crown Cork and Seal Company
Baltimore, Maryland

E. R. FLEMING
Electrical Maintenance Foreman
Power and Fuel Division
Carnegie-Illinois Steel Corporation
Gary, Indiana

W. C. FORK
Superintendent, Hot Mills
Acme Steel Company
Chicago, Illinois

L. L. FRERET
Mechanical Engineer
American Rolling Mill Company
Ashland, Kentucky

A. J. HARRIS
Superintendent Industrial Engineering Dept.
Pittsburgh Steel Company
Monessen, Pennsylvania

W. G. HOBSTETTER
Chief Engineer
Wheeling Steel Corporation
Benwood, West Virginia

R. W. HODIL
Superintendent Sheet Galvanizing Department
Youngstown Sheet and Tube Company
Youngstown, Ohio

W. E. HYDE
Lubrication Engineer
Wheeling Steel Corporation
Steubenville, Ohio

H. E. JONES
Assistant General Foreman
Electrical and Mechanical Power and Fuel Div.
Carnegie-Illinois Steel Corporation
Gary, Indiana

P. H. KIMBERLIN
Specification Writer
Engineering Department
Carnegie-Illinois Steel Corporation
Chicago, Illinois

D. M. KINNEBURGH
Assistant Superintendent Maintenance
Carnegie-Illinois Steel Corporation
Gary, Indiana

C. V. LAUER
Assistant Superintendent, Blast Furnaces
Carnegie-Illinois Steel Corporation
Gary, Indiana

W. W. MCROY
Tin Plate Metallurgist
Youngstown Sheet and Tube Company
East Chicago, Indiana

P. V. MARTIN
Assistant Division Superintendent
Coke Plant and Blast Furnace
Carnegie-Illinois Steel Corporation
Gary, Indiana

J. M. READ
Assistant Superintendent
Cold Strip Tin Department
Republic Steel Corporation
Niles, Ohio

W. M. RICHMOND
Electrical Foreman
Power and Fuel Division
Carnegie-Illinois Steel Corporation
Gary, Indiana

J. M. ROSS
Mechanical Foreman
Construction Department
Tennessee Coal, Iron and Railroad Company
Fairfield, Alabama

F. M. SCHARFF
Roll Designer
National Tube Company
Lorain, Ohio

F. K. SCHEFE
Chief Engineer
Carnegie-Illinois Steel Corporation
Gary, Indiana

H. A. SHERER
Chief Engineer
Reeves Steel and Manufacturing Company
Dover, Ohio

J. A. SMITH
Works Industrial Engineer
Tennessee Coal, Iron and Railroad Company
Birmingham, Alabama

PAUL SPANGLER
Assistant Superintendent
Cold Strip Department
Youngstown Sheet and Tube Company
East Chicago, Indiana

W. H. TAYLOR
Maintenance Foreman, Tin Mill
Tennessee Coal, Iron and Railroad Company
Fairfield, Alabama

R. P. TOOKE
Works Engineer
American Rolling Mill Company
Butler, Pennsylvania

J. C. UNDERWOOD
Operative and Maintenance Foreman
Electric and Fuel Division
Carnegie-Illinois Steel Corporation
Gary, Indiana

R. H. WESTERBERG
Chief Inspector
Sheet and Tin Mills
Carnegie-Illinois Steel Corporation
Gary, Indiana

L. L. WHITNEY, JR.
Metallurgist
Inland Steel Company
East Chicago, Indiana

W. E. WILLIAMS
Maintenance Foreman
Tennessee Coal, Iron and Railroad Company
Fairfield, Alabama

P. J. WILSON
General Maintenance Foreman
Sheet Mill, Cold Reduction
Carnegie-Illinois Steel Corporation
Gary Sheet and Tin Mill
Gary, Indiana

W. H. YECKLEY
Superintendent Open Hearth
Youngstown Sheet and Tube Company
Youngstown, Ohio

DONALD YOUSE
Cost Analyst
Carnegie-Illinois Steel Corporation
Pittsburgh, Pennsylvania

K. W. HARRIS
Electrical Squad Leader
Republic Steel Corporation
Engineering Department
Warren, Ohio

D. H. HAIGHT
Turn Foreman
Cold Reduction Tin Mill
Tennessee Coal, Iron and Railroad Company
Birmingham, Alabama

O. K. MOYNIHAN
Assistant Superintendent, Cold Strip Mill
Wheeling Steel Corporation
Yorkville, Ohio

R. A. FOREMAN
Assistant Maintenance Foreman
Carnegie-Illinois Steel Corporation
Irvin Works, Dravosburg, Pennsylvania

W. L. BARR
Chief Engineer
Follansbee Steel Corporation
Follansbee, West Virginia

W. C. GREENLEAF
Mill Metallurgist
Youngstown Sheet and Tube Company
East Chicago, Indiana

T. G. SIMISON
Superintendent 54 in. Hot Strip Department
Youngstown Sheet and Tube Company
East Chicago, Indiana

S. Ryhagen
Assistant Superintendent
Cold Rolling Department
Sandvikens Ternverks A/B
Sandviken, Sweden

F. E. Stephens
Assistant Combustion Engineer
Republic Steel Corporation
Corrigan McKinney Division
Cleveland, Ohio

J. A. Batz
Cold Mill Master Mechanic
Jones and Laughlin Steel Corporation
Pittsburgh, Pennsylvania

G. R. Walter
Chief Electrician
American Smelting and Refining Company
Baltimore, Maryland

G. A. Bahm
Superintendent Shops
Youngstown Sheet and Tube Company
Youngstown, Ohio

Emil Wrage
Chief Engineer
Globe Steel Tubes Company
Milwaukee, Wisconsin

H. M. Williams
Assistant Superintendent
Cold Strip Department, Tin Mill
Youngstown Sheet and Tube Company
East Chicago, Indiana

David Jones
Rolling Foreman
Cold Reduction Sheet Section
Richard Thomas and Company, Ltd.
Ebbw. Vale, Mon., England

I. Williams
Supervisor
Hot Rolled Sheet Section
Richard Thomas and Company Limited
Ebbw Vale, Mon., England

C. Gwynne
Supervisor
Cold Sheet Section
Richard Thomas and Company Limited
Ebbw Vale, Mon., England

J. S. Maclean
Supervisor
Tin Plate Cold Reduction
Richard Thomas and Company Limited
Ebbw Vale, Mon., England

V. W. Fugate
General Foreman
Labor and Track Departments
Carnegie-Illinois Steel Corporation
Homestead Works
Munhall, Pennsylvania

W. T. Smith
Assistant Superintendent
Maintenance Department
Carnegie-Illinois Steel Corporation
Munhall, Pennsylvania

C. J. Degenhardt
Maintenance Foreman
Carnegie-Illinois Steel Corporation
Munhall, Pennsylvania

A. F. Schoenstein
Electrical Engineering Draftsman
Jones and Laughlin Steel Corporation
Pittsburgh, Pennsylvania

E. W. Welch
Foreman
Tractor Division
Carnegie-Illinois Steel Corporation
Gary Sheet Mill
Gary, Indiana

E. Shay
Assistant Foreman
Electrical Construction
Carnegie-Illinois Steel Corporation
Gary Sheet Mill
Gary, Indiana

R. E. King
General Foreman
Electrical Department
Carnegie-Illinois Steel Corporation
Gary Sheet Mill
Gary, Indiana

J. R. Thompson
Power Foreman
Carnegie-Illinois Steel Corporation
Gary Sheet Mill
Gary, Indiana

W. F. Bachmann
General Foreman
Electrical Maintenance
Carnegie-Illinois Steel Corporation
Gary Sheet Mill
Gary, Indiana

W. N. Smith
Special Examiner
Sheet and Strip Steel
Carnegie-Illinois Steel Corporation
Gary, Indiana

G. R. Elder, Jr.
Electrical Turn Foreman
Republic Steel Corporation
Cleveland, Ohio

N. Hamilton
Metallurgical Engineer
Babcock and Wilcox Tube Company
Beaver, Pennsylvania

N. L. Bock
Chief Engineer
Bethlehem Steel Company
Los Angeles, California

C. F. Black
Assistant to Combustion Engineer
98 in. Strip Mill
Republic Steel Corporation
Cleveland, Ohio

E. S. Silva
Technical Director
National Steel Company
Rio de Janeiro, Brazil

H. R. Turner
Master Mechanic
Bethlehem Steel Company
Strip and Sheet Division
Lackawanna, New York

W. H. A. Robertson
Managing Director
W. H. A. Robertson and Company, Ltd.
Lynton Works, Bedford, England

J. Norvell Von Behren
Project Engineer
Carnegie-Illinois Steel Corporation
Duquesne, Pennsylvania

I. W. Gray
General Electrical Foreman
Strip Mill
Republic Steel Corporation
Cleveland, Ohio

W. A. Thiel
Master Mechanic
American Bridge Company
Gary, Indiana

Associate

H. Henriques
Manufacturers Agent
Philadelphia, Pennsylvania

T. A. Buck
Sales Engineer
General Electric Company
Pittsburgh, Pennsylvania

R. M. Beck
Sales Engineer
Aluminum Company of America
Pittsburgh, Pennsylvania

W. K. Schlotterbeck
Sales Engineer
Reliance Electric and Engineering Company
Philadelphia, Pennsylvania

Purlee Ruff
Sales Engineer
Tide Water Associated Oil Company
Pittsburgh, Pennsylvania

C. A. Dutton
Industrial Power and Heating Superintendent
Buffalo Niagara Electric Corporation
Buffalo, New York

L. H. Connell
Staff Engineer, Sales Department
Detroit Edison Company
Detroit, Michigan

L. J. Zindar
Sales Engineer
Cutler-Hammer, Inc.
Detroit, Michigan

C. C. Frampton
Sales Engineer
Westinghouse Electric and Manufacturing Co.
Pittsburgh, Pennsylvania

B. G. Forbes
Electrical Engineer
Bridgeport Brass Company
Bridgeport, Connecticut

W. Kilpatrick
Director and General Manager
Davy and United Engineering Company Ltd.
Sheffield, England

S. J. Nogosek
Sales Engineer
Clark Controller Company
Chicago, Illinois

P. J. Shepherd
Sales Engineer
National Carbon Company
Cleveland, Ohio

J. P. Benz
District Sales Manager
Palmer-Bee Company
Pittsburgh, Pennsylvania

M. S. Carlson
Switchgear Specialist
I.T.E. Circuit Breaker Company
Philadelphia, Pennsylvania

F. D. Clark
District Manager
Bantam Bearings Corporation
Cleveland, Ohio

G. M. Comstock
Sales Engineer
L. J. Wing Manufacturing Company
Pittsburgh, Pennsylvania

O. A. Eger
Sales Engineer
Lewis Foundry and Machine Company
Pittsburgh, Pennsylvania

J. W. Haygood
Service Supervisor
Linde Air Products Company
Pittsburgh, Pennsylvania

H. F. Hunter
Owner
H. F. Hunter Sales
Pittsburgh, Pennsylvania

P. H. Kreuscher
Experimental Engineer, Strip Mill
Lewis Foundry and Machine Company
Pittsburgh, Pennsylvania

C. M. Muchnic
Representative
United Engineering and Foundry Company
Pittsburgh, Pennsylvania

A. L. Munson
Sales
National Carbon Company
Pittsburgh, Pennsylvania

W. B. Nicholson
District Engineer
Linde Air Products Company
Pittsburgh, Pennsylvania

H. W. Potter
Metallurgist
Arthur G. McKee and Company
Cleveland, Ohio

T. B. Ryan
Sales Engineer
Dingle-Clark Company
Philadelphia, Pennsylvania

Paul H. Semler
Roll Sales
United Engineering and Foundry Company
Pittsburgh, Pennsylvania

K. H. Sievers
Sales Engineer
Wagner Electric Corporation
Chicago, Illinois

K. L. Wilson
Industrial Manager
Brown Instrument Company
Cleveland, Ohio

ITEMS OF INTEREST

N. J. Clarke, vice president in charge of sales, Republic Steel Corporation, Cleveland, has been elected president, Republic Supply Company, Houston, Texas, a wholly-owned subsidiary of Republic Steel Corporation. **A. B. Judd,** vice president of the company, has been elected vice president and general manager. Other officers are: **J. H. Brooks,** vice president, and **J. N. Lollar, Jr.,** secretary and treasurer.

George N. Harmon has been promoted to assistant district manager of the Warren-Niles District of Republic Steel Corporation.

Mr. Harmon succeeds **B. W. Norton,** who was recently named general superintendent of blast furnaces and mines in Republic's Southern District, with headquarters in Birmingham.

Born in Kittanning, Pennsylvania, Mr. Harmon attended the schools at Karns City, Pennsylvania. He started immediately in the steel industry, his first job being with the Standard Steel Car Company of Butler, Pennsylvania. In 1916 he joined the Forged Steel Wheel Company, also of Butler, as electrician's helper, and a year later was promoted to turn foreman. In 1919 he went with the Trumbull Steel Company of Warren, as turn foreman of the steel works, and in 1920 was promoted to general foreman of that department. He was made assistant superintendent of the electrical department in 1925, and in 1931, after the Trumbull Steel Company had become part of Republic Steel Corporation, he was named superintendent of the electrical department of the Warren District.

In 1938 Mr. Harmon was named superintendent of the Niles strip tin department and in 1940, general superintendent of the sheet and tin departments of the Warren and Niles Works. Mr. Harmon has been an active member of the Association for many years.

The Carnegie-Illinois Steel Corporation recently announced the following personnel changes at their Gary, Indiana works:

H. S. Brink, formerly assistant plant industrial engineer, has been named plant industrial engineer. **E. H. Gott** has been transferred from the industrial engineering department to the maintenance department where he is assistant division superintendent of maintenance. **J. F. Frain,** formerly superintendent of the 12 in. No. 1 merchant mill, becomes superintendent of the 44 in. blooming and 36 in. slab mill. **W. N. Nagel,** who was assistant to division superintendent of the plant maintenance division, has been appointed assistant plant industrial engineer. **F. L. Collins,** formerly assistant division superintendent of power and fuel, becomes electrical engineer. **H. R. Middlebrook,** formerly assistant division superintendent of maintenance has been appointed assistant division superintendent, power and fuel.

E. G. Price has been named general superintendent, Lorain, Ohio, plant, National Tube Company, Pittsburgh, succeeding **Earl W. Brown,** superintendent for the last eleven years. Mr. Brown goes to the Pittsburgh plant where he will join the staff of E. N. Sanders, vice-president in charge of operations.

Ward F. Simmons, metallurgical engineer, formerly associated with American Steel and Wire Company at Duluth, has joined the technical staff of Battelle Memorial Institute, Columbus, Ohio.

Leo A. Behrendt has joined the Crucible Division of the Joseph Dixon Crucible Company in Jersey City, New Jersey.

His early years were spent in laboratory work in the Terra-Cotta Industry. He served in the Aviation Corps of the A.E.F. throughout World War I, following which he completed special ceramic engineering courses at the University of Illinois.

In 1926 he became superintendent of the Chicago Crucible Company, which in 1930 merged with the Naugatuck Valley Crucible Company, as the Chicago-

A. F. GEISE

G. N. HARMON

H. R. MIDDLEBROOK

Naugatuck Crucible Company, changing its name in 1934 to the American Crucible Company.

In 1936 he became a director, also vice president and plant manager of the latter company, continuing until his resignation.

▲

A modern X-ray machine has been selected by leaders of the borough of Rotherham, England, as about the most precious gift they could ask of an American son of one of their old steel-making families. The selection was made in reply to an offer by **C. W. Heppenstall,** veteran Pittsburgh steel magnate, and the machine soon will be on its way across the Atlantic.

Mr. Heppenstall, whose family has been in the steel business in Rotherham for 150 years, made his offer to Alfred R. Habershon, former lord mayor and head of a large steel concern there. Replying, Habershon said associates believed the X-ray machine would make an ideal gift and added: "Rotherham has been lucky so far; we have had some air raids but the casualties here have not been unduly heavy. I am afraid I cannot enter into details or the censor will return this letter."

A. Blenkinsop, chairman of the Rotherham hospital, had more to say, disclosing his institution has been handling 10,000 casualties a year since the outbreak of the war. Thanking Heppenstall for the gift, he wrote: "There is nothing which would prove a greater boon. Our X-ray apparatus has been in use approximately 15 years, and we have for some time been considering an extension of the department but reluctantly decided we could not afford the expense. We are about to establish a special department for the treatment of fracture and bone injuries generally, so therefore you will appreciate that this handsome gift has come at a most opportune time."

Efforts first were made to get the X-ray machine in England, but it was found none was available. The purchase was made through the branch of an American firm, which will ship the machine as quickly as possible.

Rotherham, situated five miles outside the great steel center of Sheffield, has a population of approximately 85,000 persons. Because it has no cathedral it is only a borough, an English city being restricted to those communities with cathedrals.

Mr. Heppenstall is 69, and president and treasurer of the Heppenstall Company, which manufactures high grade alloy and carbon steel. His father, Sam Heppenstall, a native of Rotherham, helped found the company in Pittsburgh in 1889 as the Trethewey Manufacturing Company.

After attending Indiana State Normal School and later the Pennsylvania State College, where he won a gold football which he still wears, Mr. Heppenstall became general superintendent of the company. In 1920 he was made president.

C. W. HEPPENSTALL

"gives an X-Ray machine to England"

R. H. Musser, for the last four years assistant district sales manager of the Chicago office of the Heppenstall Company, has been appointed manager of the priorities department of the company with headquarters in Pittsburgh, according to S. B. Heppenstall, Jr., general manager of sales.

R. H. MUSSER

Edgar F. Heckert, manager, service department, York Ice Machinery Corporation, York, Pennsylvania, has been appointed special assistant to the general works manager. Mr. Heckert oftained a B.S. in electrical engineering at Pennsylvania State College and was subsequently an employe of General Electric Company, engaged in electrical testing, and Southern Utilities Corporation, as construction engineer. He joined York (then the York Manufacturing Company) in 1909 as a student installation engineer, and several years

later became assistant manager of the service department, where he recently became manager.

G. H. Bendell, who has been superintendent at the Waukegan, Illinois, works of the American Steel & Wire Company, Pittsburgh, subsidiary of the United States Steel Corporation, has been transferred to Joliet as assistant general superintendent of Joliet operations.

S. R. Snow, formerly assistant superintendent at Waukegan, has been made general superintendent. Mr. Snow's place is being taken by **J. R. Gaut,** who is being transferred from the vice-president's office in Cleveland.

Van H. Leichliter, formerly superintendent of wire mill, Cuyahoga works, American Steel & Wire Company, Cleveland, has been appointed superintendent, wire mills, South works, Worcester, succeeding **F. P. Leahey,** who has been appointed superintendent, wire mill, Cuyahoga works.

H. W. Graham, director of research for Jones & Laughlin Steel Corp., Pittsburgh, Pa., has been named chairman of the Committee on Iron and Steel of the National Research Council's South American Committee, Maurice Holland, director of the National Research Council's Division of Engineering and Industrial Research announced.

Obituaries

Walter Greenwood, aged 94, one of the pioneer safety workers in the steel industry, died at his home in Youngstown, Ohio, September 29. Born in Girard, Pennsylvania, Mr. Greenwood led a varied career following Civil War service in the United States Navy, working in the oil industry, on the railroads, as farmer, shoemaker, telegraph operator, and in private business. He was safety engineer for the Carnegie Steel Company for 21 years, retiring in 1928, at the age of 81. He was the oldest man on the pension rolls of the corporation.

Mr. Greenwood was a member of long standing in the Association of Iron and Steel Engineers, and maintained his interest in their activities on through his years of retirement, having attended the 1941 Spring Conference in Youngstown.

Le Roy Kells, sales engineer for The Wellman Engineering Company, died suddenly at his home in Cleveland Heights on October 4. In apparently excellent health until the time of his death at the age of fifty-one, the news came as an unpleasant surprise to his many friends and associates in the steel and allied industries.

After graduating from Ohio State University, Mr. Kells went with the Pennsylvania Railroad, then with the Chapman Stein Company of Mt. Vernon, Ohio, being chief engineer when absorbed by Surface Combustion Company. He was with Surface Combustion for four years, later going with the Salem Engineering Company, holding the position of sales engineer and later chief engineer until becoming associated with The Wellman Engineering Company in October 1940.

WORLD'S GREATEST all around ELECTRIC TOOL

DRILLS—GRINDS—SANDS
SAWS—POLISHES
SHARPENS—CARVES

The new WHIZ ELECTRIC TOOL is the handiest power tool ever made. A rugged tool for power and precision work. Drills through ¼ inch iron plate in 42 seconds or engraves intricate designs. Handles any material: Metals—Woods—Alloys—Plastics—Glass—Steel—etc. Saves time. Eliminates labor. Plug into any socket AC or DC, 110 volts. Chuck ¼ inch capacity. Ball bearing thrust. Powerful, triple-geared motor. STANDARD MODEL, with Normal Speed (uses 200 different accessories, instantly interchangeable). **Price only $7.95.**

The only DRILL-TOOL with a full year's guarantee

FREE Accessory outfit (Value $2) includes set of drills, mounted 1½ inch grinder, sanding discs, cutting wheels, mounted brush, polishing wheel, carving burr, etc. FREE with each tool ordered NOW. We pay postage.

10-DAY TRIAL—MONEY BACK GUARANTEE

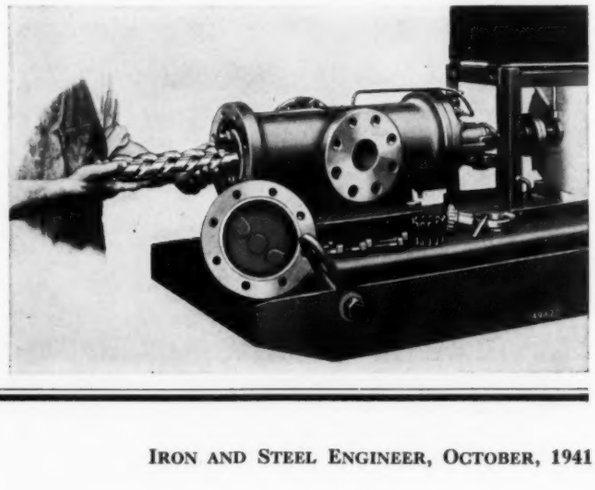
PARAMOUNT PRODUCTS CO.

Dept. 10-RAS 545 Fifth Ave. New York, N. Y.

The three moving parts of the DE LAVAL-IMO OIL PUMP

can at once be withdrawn upon removing the end cover and releasing the coupling half. There are no valves, no timing gears and only one stuffing box, which is under suction pressure only. Simplicity in construction is matched by smoothness in operation, there is no vibration or pulsation, and the pump can be coupled to a standard speed motor or turbine.

Write for Catalog I-74.

IMO
I MOVE OIL

IMO PUMP DIVISION
of the De Laval Steam Turbine Co.
Trenton, N. J.